Food Safety in China

Food Safety in China

Science, Technology, Management and Regulation

Edited by

Joseph J. Jen
California Polytechnic State
University, CA
USA

Junshi Chen
China National Center for Food Safety Risk Assessment
Bejing, China

WILEY

This edition first published 2017 © 2017 John Wiley & Sons Ltd

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system, or transmitted, in any form or by any means, electronic, mechanical, photocopying, recording or otherwise, except as permitted by law. Advice on how to obtain permision to reuse material from this title is available at http://www.wiley.com/go/permissions.

The right of Joseph J. Jen and Junshi Chen to be identified as the author of the editorial material in this work has been asserted in accordance with law.

Registered Offices
John Wiley & Sons Ltd, The Atrium, Southern Gate, Chichester, West Sussex, PO19 8SQ, UK

Editorial Office
111 River Street, Hoboken, NJ 07030, USA
9600 Garsington Road, Oxford, OX4 2DQ, UK
The Atrium, Southern Gate, Chichester, West Sussex, PO19 8SQ, UK
Boschstr. 12, 69469 Weinheim, Germany

For details of our global editorial offices, customer services, and more information about Wiley products visit us at www.wiley.com.

Wiley also publishes its books in a variety of electronic formats and by print-on-demand. Some content that appears in standard print versions of this book may not be available in other formats.

Limit of Liability/Disclaimer of Warranty
The publisher and the authors make no representations or warranties with respect to the accuracy or completeness of the contents of this work and specifically disclaim all warranties, including without limitation any implied warranties of fitness for a particular purpose. This work is sold with the understanding that the publisher is not engaged in rendering professional services. The advice and strategies contained herein may not be suitable for every situation. In view of ongoing research, equipment modifications, changes in governmental regulations, and the constant flow of information relating to the use of experimental reagents, equipment, and devices, the reader is urged to review and evaluate the information provided in the package insert or instructions for each chemical, piece of equipment, reagent, or device for, among other things, any changes in the instructions or indication of usage and for added warnings and precautions. The fact that an organization or website is referred to in this work as a citation and/or potential source of further information does not mean that the author or the publisher endorses the information the organization or website may provide or recommendations it may make. Further, readers should be aware that websites listed in this work may have changed or disappeared between when this works was written and when it is read. No warranty may be created or extended by any promotional statements for this work. Neither the publisher nor the author shall be liable for any damages arising herefrom.

Library of Congress Cataloging-in-Publication data applied for

ISBN: 9781119237969

Cover Design: Wiley
Cover image: © RichLegg/Gettyimages

Set in 10/12pt Warnock by SPi Global, Chennai, India

10 9 8 7 6 5 4 3 2 1

Contents

List of Contributors

Dr. Shawn S. Arita
Economist
Economic Research Service
US Department of Agriculture
Washington DC
USA

Dr. Li Bai
Department Chairperson and Professor of Consumer Behaviors
Department of Agricultural and Forestry Economics and Management
College of Biological and Agricultural Engineering
Jilin University
Changchun
Jilin Province
China

Dr. Xue Bai
Associate Professor
Key Laboratory for Zoonosis Research
Ministry of Education
Institute of Zoonosis
Jilin University
Changchun
Jilin Province
China

Dr. Pascal Boireau
Director and Professor
Paris East University
ANSES
INRA
ENVA
Laboratory for Animal Health
Maisons-Alfort
France

Dr. Jennifer L. Cannon
Adjunct Associate Professor of Food Virology
Center for Food Safety
University of Georgia
Griffin
Georgia
USA

Dr. Fang Chen
Professor of Food Safety
College of Food Science and Nutritional Engineering
China Agricultural University
Haidian District
Beijing
China

Dr. Hongda Chen
National Program Leader
Bioprocessing Engineering and Nanotechnology
National Institute of Food and Agriculture
US Department of Agriculture
Washington
DC
USA

Dr. Jiaxu Chen
Chief
National Institute of Parasitic Diseases
Chinese Center for Disease Control and Prevention
Shanghai
China

Dr. Junshi Chen
Senior Advisor
China National Center for Food Safety Risk Assessment
Beijing
China

Dr. Rongfang Chen
Associate Professor of Food Safety
General Enforcement Team
Shanghai Municipal Food and Drug Administration
Shanghai
China

Mr. Zhao Chen
Ph.D. Candidate in Microbial Food Safety
Department of Biological Sciences
Clemson University
Clemson
SC
USA

Dr. P. Michael Davidson
Institute Chancellor's Professor Emeritus
Department of Food Science and Technology
University of Tennessee
Coeur d'Alene
ID
USA

Dr. Qingli Dong
Associate Professor of Predictive Microbiology
Institute of Food Quality and Safety
University of Shanghai for Science and Technology
Shanghai
China

Dr. Yongxiang Fan
Professor
Center for Food Safety Standard
China National Center for Food Safety Risk Assessment
Beijing
China

Dr. Seamus Fanning
Distinguished Professor
UCD-Centre fornFood Safety
University College Dublin
Ireland

Dr. Fred Gale
Senior Economist
Economic Research Service
US Department of Agriculture
Washington DC
USA

Dr. Samuel Godefroy
Full Professor
Food Risk Analysis and Regulatory Policies
Department of Food Science
Food Risk Analysis and Regulatory Excellence Platform
Institute of Nutrition and Functional Foods
University Laval
Quebec City
QC
Canada

Dr. Shunlong Gong
Associate Dean
School of Management
Jilin University
Changchun
China

Dr. Yunyun Gong
Associate Professor
School of Food Science and Nutrition
University of Leeds
United Kingdom

Dr. Zhenhua Gu
President
Shanghai Food Safety Federation
Shanghai
China

Dr. Boli Guo
Professor
Institute of Food Science and Technology
China Academy of Agricultural Sciences
Ministry of Agriculture
Beijing
China

Dr. Yunchang Guo
Division of Foodborne Diseases Surveillance
China National Center for Food Safety Risk Assessment
Beijing
China

Dr. Chi-Tang Ho
Distinguished Professor of Food Chemistry
Rutgers University
New Brunswick
NJ
USA

Dr. Sandra Hoffmann
Senior Economist
Economic Research Service
US Department of Agriculture
Washington DC
USA

Dr. Bo-Yang Hsu
Assistant Professor
Department of Food and Beverage Management
Lee-Ming Institute of Technology
New Taipei City
Taiwan

Dr. Xiaosong Hu
Dean and Professor of Fruit and Vegetable Processing
College of Food Science and Nutritional Engineering
China Agricultural University
Beijing
China

Dr. Jinlin Huang
Professor
Yangzhou University
Yangzhou
Jiangsu Province
China

Dr. Yao-wen Huang
Professor Emeritus
Department of Food Science and Technology
University of Georgia
USA

Dr. Lucy Sun Hwang
Professor Emeritus
Graduate Institute of Food Science and Technology
National Taiwan University
Taipei
Taiwan

Dr. Joseph J. Jen
California Polytechnic State University
San Luis Obispo
CA
USA

Dr. Lianzhou Jiang
Dean
College of Food Science
Northeast Agricultural University
Harbin
Heilongjiang Province
China

Dr. Yujun Jiang
Professor of Dairy Science
College of Food Science
Northeast Agricultural University
Harbin
Heilongjiang Province
China

Dr. Xinan Jiao
President and Professor of Microbial Hazards
Yangzhou University
Yangzhou
Jiangsu Province
China

Ms. Wei Kang
Former Graduate Student
Department of Food Science and Technology
University of Georgia
Griffin
GA
USA

Dr. Felicia Kow
Senior Researcher
Institute of Marine and Antarctic Sciences
University of Tasmania
Launceston
Tasmania
Australia

Dr. Fengqin Li
Professor
The Microbiology Laboratory
China National Center for Food Safety Risk Assessment
Beijing
China

Dr. Ning Li
China National Center for Food Safety Risk Assessment
Beijing
China

Dr. Yang Li
Professor
College of Food Science
Northeast Agricultural University
Harbin
Heilongjiang Province
China

Dr. Hongyan Liu
Institute of Food Science and Technology
China Agricultural Academy of Sciences
Ministry of Agriculture
Beijing
China

Dr. Junrong Liu
Professor of Seafood Technology
Quality and Safety
College of Food Science and Engineering
Dalian Ocean University
Dalian
Liaoning Province
China

Ms. Lingling Liu
Ph.D. Candidate in Food Science
Department of Food Science and Technology
University of Georgia
Griffin
GA
USA

Dr. Mingyuan Liu
Director
Key Laboratory for Zoonosis Research
Ministry of Education
Institute of Zoonosis
Jilin University
Changchun
China

Dr. Xiaolei Liu
Associate Professor
Key Laboratory for Zoonosis Research
Ministry of Education
Institute of Zoonosis
Jilin University
Changchun
China

Dr. Zhaoping Liu
China National Center for Food Safety Risk Assessment
Beijing
China

Dr. Yaguang Luo
Food Quality and Environmental Microbial and Food Safety Laboratories
Beltsville Agricultural Research Center
Agricultural Research Service
US Department of Agriculture
Beltsville
MD
USA

Dr. Yunbo Luo
Former Dean and Professor
College of Food Science and Nutritional Engineering
China Agricultural University
Beijing
China

Mr. Zhaohui Ma
Deputy Director
Department of Food Safety Supervision II
China Food and Drug Administration
Beijing
China

Dr. Xuedan Mao
Associate Professor
Center for Food Safety Standard Division 1
China National Center for Food Safety Risk Assessment
Beijing
China

Ms. Suhe Meng
Chairperson of the Board
Chinese Institute of Food Science and Technology
Beijing
China

Dr. Hong Miao
Professor and Deputy Director
Division 4 of Center for Food Safety Standard
China National Center for Food Safety Risk Assessment
Beijing
China

Dr. Douglas C. Moyer
Assistant Professor
College of Human Medicine
Michigan State University
East Lansing
MI
USA

Lawrence Pacquette
Regional Head R&D and Scientific Affairs
Columbus
OH
USA

Dr. Baokun Qi
College of Food Science
Northeast Agricultural University
Harbin
Heilongjiang Province
China

Dr. Xiongwu Qiao
President and Professor of Pesticide Chemistry
Shanxi Academy of Agricultural Sciences
Taiyuan
Shanxi Province
China

Dr. Congqian Qiu
Associate Professor of Food Safety
General Enforcement Team of Shanghai Food and Drug Administration
Shanghai
China

Dr. Sheng Quan
School of Life Sciences and Biotechnology
Shanghai Jiao Tong University
Shanghai
China

Dr. Michael N. Routledge
Associate Professor of Envirnmental Toxicology
School of Medicine
University of Leeds
United Kingdom

Mr. Daniel Schmitz
Regional Head R&D and Scientific Affairs
Abbott Nutrition
Columbus
OH
USA

Dr. Bing Shao
Professor of Analytical Chemistry
Central Laboratory
Beijing Center for Disease Prevention and Control
Beijing
China

Dr. Xianming Shi
Chairman and Professor of Food Microbiology
Department of Food Science and Technology
School of Agriculture and Biology
Shanghai Jiao Tong University
Shanghai
China

Dr. John W. Spink
Director and Assistant Professor
Food Fraud Initiative
College of Veterinary Medicine
Michigan State University
East Lansing
MI
USA

Fabrizis Suarrez
Professor
Regional Head R&D and Scientific Affairs
Columbus
OH
USA

Dr. Xiaonan Sui
Professor
College of Food Science
Northeast Agricultural University
Harbin
Heilongjiang Province
China

Dr. Baoguo Sun
President and Professor
School of Food and Chemical Engineering
Beijing Technology and Business University
Beijing
China

Dr. Ronald Keith Tume
Honorary Guest Professor
National Center of Meat Quality and Safety Control
Nanjing Agricultural University
Nanjing
Jiangsu Province
China

Dr. Duncan Lap-Yan Tung
Center of Food Safety and Environment Hygiene Department
Hong Kong

Dr. Liqi Wang
Lecturer
College of Animal Science and Veterinary Medicine
Jiangxi Agricultural University
Nanchang
China

Jing Wang
Professor of Food Additives
School of Food and Chemical Engineering
Beijing Technology and Business University
Beijing
China

Ms. Pan Wang
Ph.D. Candidate in Food and Nutrition
College of Food Science and Nutritional Engineering
China Agricultural University
Beijing
China

Dr. Yu Wang
Assistant Professor
Food Science and Human Nutrition
Citrus Research and Education Center
University of Florida
Lake Alfred
FL
USA

Dr. Zhongjiang Wang
College of Food Science
Northeast Agricultural University
Harbin
Heilongjiang Province
China

Dr. Zhutian Wang
Director
Center for Food Safety Standard
China National Center for Food Safety Risk Assessment
Beijing
China

Dr. Shuai Wei
Institute of Food Science and Technology
China Academy of Agricultural Sciences
Ministry of Education
Beijing
China

Dr. Yimin Wei
Institute of Food Science and Technology
Chinese Academy of Agricultural Sciences
Ministry of Education
Beijing
China

Dr. Guangfeng Wu
Associate Professor
College of Food Science and Nutritional Engineering
China Agricultural University
Beijing
China

Dr. Shuyu Wu
Medical Research Scientist
China Office
US Centers for Disease Control and Prevention
Beijing
China

Dr. Xiuping Wu
Associate Professor
National Institute of Parasitic Diseases
Chinese Center for Disease Control and Prevention
Shanghai
China

Dr. Yongning Wu
Chief Scientist
China National Center for Food Safety Risk Assessment
Beijing
China

Dr. Yanping Xie
Molecular Characterization of Foodborne Pathogen Research Unit
Eastern Regional Research Center
Agricultural Research Service
US Department of Agriculture
Wyndmoor
PA
USA

Dr. Zhinong Yan
Food Safety Director of Asia Pacific Region
Ecolab (China) Investment Co., Ltd.
Shanghai
China

Dr. Dajin Yang
Researcher
Risk Surveillance Division 1
China National Center for Food Safety Risk Assessment
Beijing
China

Dr. Fan Yang
Associate Professor
Department of Basic Veterinary Science
College of Animal Science and Technology
Henan University of Science and Technology
Louyang
China

Dr. Litao Yang
School of Life Science and Technology
Shanghai Jiao Tong University
Shanghai
China

Dr. Keping Ye
National Center of Meat Quality and Safety Control
Nanjing Agricultural University
Nanjing
China

Dr. Jin Yue
Deputy Director
Bor S. Luh Food Safety Research Center
College of Agriculture and Biology
Shanghai Jiao Tong University
Shanghai
China

Dr. Zhenling Zeng
Director and Professor
National Reference Laboratory of Veterinary Drug Residues
South China Agricultural University
Guangzhou
China

Dr. Boce Zhang
Assistant Professor
Department of Clinical Laboratory and Nutritional Sciences
University of Massachusetts
Lowell
MA
USA

Dr. Dabing Zhang
Professor
School of Life Science and Technology
Shanghai Jiao Tong University
Shanghai
China

Dr. Jianrong Zhang
Office of Food Additive Safety
Center for Food Safety and Applied Nutrition
Food and Drug Administration
College Park
MD
USA

Dr. Jing Zhang
Associate Professor
Central Laboratory
Beijing Center for Disease Prevention and Control
Beijing
China

Dr. Yan Zhang
Food Science and Technology Programme
Department of Chemistry
National University of Singapore
Singapore

Ms. Zhe Zhang
Assistant Professor
Center of Food Safety Standard
China National Center for Food Safety Risk Assessment
Beijing
China

Dr. Zhiqiang Zhang
Department of Food Safety Standards
Risk Surveillance and Assessment
National Health and Family Planning Commission
China

Dr. Kai Zhao
Chemical Foreign Economic Cooperation Center
Beijing
China

Dr. Yanyun Zhao
Professor of Food Processing and Packaging Sciences
Department of Food Science and Technology
Oregon State University
Corvallis
OR
USA

Ms. Yue Zheng
Food Safety Specialist
Commercial Food Sanitation LLC
Haraha
LA
USA

Dr. Kai Zhong
China National Center for Food Safety Risk Assessment
Beijing
China

Dr. Guanghong Zhou
Professor of Meat Quality and Safety and President of Nanjing Agricultural University
Nanjing
China

Dr. Xiaonong Zhou
Director
National Institute of Parasitic Diseases
Chinese Center for Disease Control and Prevention
Shanghai
China

Dr. Xiujuan Zhou
Department of Food Science and Technology
School of Agriculture and Biology
Shanghai Jiao Tong University
Shanghai
China

Dr. Jianghui Zhu
Epidemiologist
Risk Assessment Division 1
China National Center for Food Safety Risk Assessment
Beijing
China

Preface

After the publication of our book, “Food Safety in China: Past, Present and Future (in Chinese),” many of our international friends requested us to edit an English companion book so they could have a resource book in the field. It seems that there has not been a book yet which covers the science, technology, management, and regulations of food safety in one volume. The rapid changes in China on food safety laws and regulations, and the adoption of science and technology will serve as a good model for people in other parts of the world to learn about the food safety situation in China.

We first thought to simply translate our Chinese book into English, but decided against the idea. Instead, we decided to produce a better book by adding a global perspective into many chapters and by adding new chapters we had wanted to cover in the Chinese book, but were unable to find appropriate authors.

The result is this book entitled “Food Safety in China: Science, Technology, Management and Regulation,”with 36 chapters in seven sections, and featuring 101 authors. More than a dozen new authors, mostly from outside of China, were added to the List of Contributors.

We realized that it is probably impossible for one book to contain all the aspects of food safety. Nevertheless, we feel that we have covered most of the essential topics concerning science, technology, management, and regulation of food safety. We also realize that with this many authors, the chapters will cover their topics in different depths and with different emphases, and there are some duplications of coverage, particularly in case studies. We have tried our best during the editing process to reduce duplications, but still preserve the original thoughts of the authors.

We want to thank all the authors for submitting their chapters in a timely manner and the Wiley editorial staff for dealing with many aspects of publishing the book. We also want to thank Mr. Denis Jen and Dr. Zeming Chen for their unconditional generous donations toward the cost of editing and the language service costs of the book.

Part 1

Introduction

1

Shared Responsibility of Food Safety

Joseph J. Jen

California Polytechnic State University, USA

1.1 Introduction

Part of the content of this chapter was adopted from the chapter I wrote for the book, *Food Safety in China: Past, Present and Future* [1]. Food safety has been a hot topic in the world in recent years. The horse meat case in the European Union (EU), the cantaloupe case in the United States of America (US) and the melamine case in China all received global attention. Although it has been the focus of attention for consumers in certain regions of the world for some time, it was not a major topic of concern for the government, food industry, media and the general public in China and the rest of the world till 2008. The turning point of global attention to food safety can be traced back to China's melamine event. More than 50,000 infants and children were hospitalized and there were six confirmed deaths due to the illegal addition of melamine to milk and infant formula [2]. The event was in the global news for a long time. The *New York Times* had a special series of reports tracing the origin of the event. The Chinese government reacted quickly and published the first "China Food Safety Law" in 2009 [3]. Many people started to ask the question: who are the people responsible for food safety?

No doubt, food safety is not the responsibility of one person, one group of people, nor of an industry or a government agency. It is the shared responsibility of many people and organizations, in fact everyone.

The term, "shared responsibility" for food safety was first coined by the World Health Organization (WHO) [4]. WHO defined shared responsibility as the "collaboration between all sectors, including government, consumer organizations and food processors to achieve a safer and wholesome food supply." The definition was inadequate to cover the whole spectrum of food safety.

The European Commission published a white paper on food safety in 2000, which led to the formation of the European Food Safety Authority (EFSA) in 2002. In the white paper, it states that "feed manufacturers, farmers, and food operators have the primary responsibility for food safety. Competent authorities monitor and enforce this responsibility through the operation of national surveillance and control systems. Consumers must also recognize that they are responsible for the proper storage, handling and

Food Safety in China: Science, Technology, Management and Regulation, First Edition.
Edited by Joseph J. Jen and Junshi Chen.

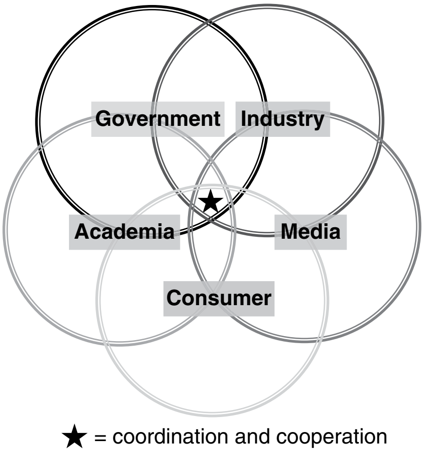


Figure 1.1 The five pillars of food safety.

cooking of foods." By this definition, only industry, government and consumers share responsibility for food safety.

Jen [5] presented a paper at the first International Forum on Food Safety in Beijing that defined food safety as a shared responsibility by all who are dealing with foods. The food industry and government agencies have a major responsibility for food safety. Academia and media have their special responsibilities. Every consumer and everyone who eats food has to share responsibility for food safety. The five pillars of food safety (Figure 1.1) are dependent on each other and form the basis for achieving maximum food safety in any organization, country, region and the world.

The agricultural and food processing industries, being the producers of food products for consumption, have to bear the major responsibility for food safety. In developed countries, the industry knows the responsibility well. They have little, if any, intentional adulteration of food causing food safety problems. Nevertheless, accidents take place from time to time. China, being in the transition period in becoming a developed country, is faced with many intentional food adulteration and food fraud problems. China's food industry has not developed a spirit of goodwill towards society and many enterprises are still driven by a "quick profit above all else" attitude. However, some large food companies are taking food safety seriously, but it takes a while for the food safety culture to spread to all company employees. Also, China's agricultural production and processing industries are still dominated by small enterprises with few employees. A merger and consolidation process into medium and large corporations will take place in the future.

Government, as the watchdog of the agricultural and food processing industries, also has a major responsibility for food safety. Government has to issue food safety laws, regulations and guidelines for the industry to follow, and to perform inspections to ensure the laws, regulations and guidelines are followed to minimize food safety incidents. In addition, government agencies need to provide funds for food safety research and education, and be transparent with the public on food safety outbreaks. Establishing laws are only the first step. Implementation of the laws, regulations and guidelines is a long-term process. The Chinese central government has done a great job in establishing laws and regulations, but is a long way to go to spread that to every corner of the vast counties, down to the town and village levels.

Academia is responsible for training food safety workers, performing food safety research and providing the correct scientific information about food safety to society, including government agencies and industry. China's education system for food safety is just in the early stages and has a long way to go to catch advanced countries of the world.

The media should report food safety events in a truthful manner and not try to cause public panic by sensationalizing minor food safety accidents. The media also shares responsibility for educating consumers on food safety knowledge, and informing the public of any new food safety laws and regulations. It should also try to report new scientific technology in layman's terms for the public to understand. China's media has experienced rapid growth in this field.

Consumers should acquire adequate food safety knowledge and practice food safety in handling foods at home. They should also report any unsanitary conditions in public eating places to the authorities. Most importantly, consumers should not spread food safety information on the Internet that is not based on scientific fact. Leighton and Sperber [6] recently published an article stating that "good consumer practices are necessary to further improve global food safety." They declared that "food safety is the responsibility of all along the farm to table continuum."

1.2 History

China's population is anticipated to peak at 1.4 billion in 2025 [7]. Traditionally, China has been concerned with food security rather than food safety. Lester Brown published his classic text *Who will feed China?* in 1995 [8]. China has only 7–9% of the world's arable land, but 20% of the world's population, as estimated by the United Nations (UN) Food and Agriculture Organization (FAO) [9]. With the successful development of hybrid rice and other cereals, and high agricultural inputs, China gained self-sufficiency in food security in the 1990s, and began to shift their nutritional diet to animal products [10], mimicking that of developed countries in Western Europe and North America.

To sustain agricultural production, the Chinese government has invested billions to support research on transgenic varieties of rice, wheat, maize, cotton, soybean, pigs, cows and sheep. However, commercialization of the genetically engineered products has not taken place, mainly due to consumer misunderstanding of the technology. Water is the other major concern in China's agricultural production. China's water and sanitation infrastructure is at a much earlier stage of development [11], and thus the risks to the food supply are much greater. Meanwhile, chemical pollution is a major threat to both agricultural land and freshwater supplies [12]. With increased input, China's use of pesticides and veterinary drugs have increased to such a level that China is now the largest producer and exporter of pesticides in the world [13]. Lastly, the excessive use of food additives and food fraud are increasingly becoming major concerns for food safety in China.

To the credit of the Chinese government, they have made tremendous efforts to reform food safety standards, laws and regulations in recent years. With a country as vast as China, the changes are slow to reach every part of the country. The UN Resident Coordinator in China [14] has suggested that the regulatory control of food safety is a shared responsibility among national, provincial and local government authorities. A clear chain of command and responsibilities, a set of common and consistent standards, and a well-coordinated central steering committee would strengthen China's implementation of existing food safety laws and regulations.

1.3 The Food Chain and Food Safety Laws

Food is simple, but food safety is complex. The food chain is a long process from farm to table. An interesting example can be drawn from the consumer dollar (Figure 1.2) published by the Economic Research Service (ERS) of the United States Department of Agriculture (USDA).

The 2014 ERS food dollar [15] shows the percentage distribution of one US consumer dollar to all industry and business when dealing with food expenditure from farm to table. It shows that the food service segment takes the largest share of the consumer spending dollar, which means this segment has the major share of the food safety responsibilities. The food processing industry, wholesalers and retail trades are next. Farmers and agribusiness only receive 10.4 cents of the consumer dollar. When government spends funds to monitor and inspect industries for the sake of food safety, it may be wise to have this consumer food dollar distribution in mind.

Besides the United Kingdom (UK), the US probably has the longest history in the world when it comes to official food safety laws and regulations. US food safety law started with the Food and Drug Act, passed by US Congress on June 30, 1906. It prohibits interstate commerce in misbranded and adulterated food, drink and drugs. The Meat Inspection Act was passed on the dame day. The USDA had been given the responsibility and authority to enforce both Acts [16]. In 1938, Congress passed the Federal Food, Drug and Cosmetic Act, which amongst others, authorized standards of identity, quality and fill-of-container for foods, and authorized the USDA to be responsible for food processing factory inspections [17].

Figure 1.2 The food dollar.

In 1940, the Food and Drug Administration (FDA) was formed and the office was transferred from the USDA to the Department of Federal Security (now the Department of Health and Human Services (HHS)). The move split the responsibility for food safety from a single agency to multiple agencies. The move was politically motivated at the time, but it forever changed the food safety governing system in the US.

To date, the USDA Food Safety Inspection Service (FSIS) and the FDA still share the major responsibility for food safety laws and regulations. FSIS is responsible for the safety of meat, poultry and egg products, and the FDA is responsible for all other foods.

There are major differences on how FSIS and the FDA carry out their responsibilities over the years. FSIS places a USDA inspector at each and every animal slaughter and poultry processing plant throughout the US. Without the approval of the USDA inspector, no product can be shipped out of the plants, thus assuring a high level of food safety. FSIS also has mandatory recall authority. If they find a particular shipment of meat or poultry products was contaminated and may harm public health, they can order the total recall of products produced from that plant for a specific period of time.

The FDA, on the other hand, has few inspectors and works with the food industry in a very friendly way. Unless notified by reports, FDA inspection of the food processing industry is infrequent. It works with the food industry more in an advisory role. They depend greatly on a self-policing system by the food processing industry to maintain food as safe as possible. It was not until 1988 that the FDA officially became an agency of the HHS.

Other US federal agencies also have minor roles in food safety. The USDA Animal and Plant Health Inspection Service (APHIS) takes care of health issues regarding import and export of live plants and animals. The US Environmental Protection Agency (EPA) regulates the pesticide residues that are allowed to be used in agricultural production.

In 1990, US Congress passed the Nutritional Labeling and Education Act [18], which gave consumers essential nutrition information on food labels. The FDA is responsible for approving labels on food products. It is very strict on what is put on the label. All information must be based on strong scientific facts and have real and not perceived health impacts to consumers.

In 2011, US Congress passed the FDA Food Safety and Modernization Act (FSMA) [19]. The FSMA provided the FDA with more enforcement authority relating to food safety standards, such as recall and inspection authorities that the FDA never had before. It also gave the FDA tools to hold imported foods to the same standards as US domestic foods. It directed the FDA to build an integrated national food safety system in partnership with the food industry and with state and local authorities. The goal of the new law is to change the old “inspection of end products” method to a new “preventive actions at every step of the food chain” operation.

China has a relatively short history in food safety laws. The first law related to food safety can be traced to 1982 when the National People’s Congress passed a temporary trial law on “food and health”. In 1996, the trial law became official law. The public health agencies of various levels of government were given responsibility to oversee and monitor food safety and hygiene. Gradually, other agencies started to get into the picture, issuing certificates for various steps along the food chain from the farm to the table [20].

In December 2006, the Chinese Agricultural Product Safety Law was announced and implemented. After four years, Han and Yuan [21] examined the law's impact on the wholesale vegetable market in China. They found that the law did improve the quality of wholesale vegetables. However, the inspection methods and number of inspectors were generally inadequate to further improve the quality and safety of vegetables sold at wholesale markets around the country.

In December, 2007, the National People's Congress started to look into the establishment of a new food safety law. After four revisions, it was announced on February 28, 2009 by the Eleventh Congress that the first "Chinese Food Safety Law" has been established, to be implemented on June 1 of the same year [3]. After the announcement, Li [20] provided an analysis of the pros and cons of the law. He noted that from public health to food safety was a major concept change in the law. The pros were led by the use of risk assessment analysis to guide the management of food safety, the establishment of food safety standards and the setup of the unsafe food products recall system. The cons were the multiple agencies, each with responsiblity for part of the farm-to-table food chain, the different standards for domestic and export foods and the lack of clear guidelines for the punishment of food safety law violators.

Li [20] noted that in recent years, several foreign countries have regrouped all agencies that monitor food safety activities into one single agency. Canada has set up the Canada Food Inspection Agency (CFIA) to monitor the health, safety and quality of Canada's agricultural, fish and food products, and to oversee the arrival of imported plants, animals and food products. The UK has created the Food Standards Agency (FSA), an independent government department responsible for food safety and hygiene across the UK. It works with the business community to produce safe food and with local authorities to enforce the food safety regulations. Time will tell if these new agencies work well in their respective countries.

To try to solve the multiple agency monitoring and inspection of food safety issues for the whole food chain, the Chinese central government established a new ministry-level agency, the Chinese Food and Drug Administration (CFDA) in 2013 [22]. It moved almost all of the authorities dealing with food safety from other agencies into this new ministry, except import/export inspection and agricultural production, which were still handled by the General Administration of Quality Supervision, Inspection and Quarantine (AQSIQ) and the Ministry of Agriculture (MOA).

1.4 Current Status

Although laws and regulations can be passed quickly, their implementation is not as easily done and may take years, depending on the cooperation of the responsible agencies, the food industry, available inspection methods and qualified personnel. Another barrier to implementation is that some government food safety laws and regulations change and update often, making it almost impossible for the food industry to keep up.

The US FSMA was passed in 2012 [19], but the implementation has not been smooth. By the end of 2015, the FDA has not yet fully implemented the FSMA, partly due to the lack of funds budgeted by US Congress, partly due to the details of working with local health agencies and food companies. Nevertheless, the FDA is now nearing completion of the task of working out all the details with individual domestic food processing companies to set up a food safety plan and record-keeping process. The FDA will look into implementing consistency of standards between imported food products and domestic food products. Countries like China, who export a lot of food products to the US will notice the difference in the coming months.

Although China has made great progress in implementing their Food Safety Law, published in February 2009, and the CFDA has set up administration offices at the province and city levels, the laws may not have reached to the town and village levels. As with any commercial commodity, food companies may seek to maximize profits and seek quick returns by using substituted ingredients for certain products, which supersedes their social responsibility. This has led to many food fraud events in China.

Some of the events did not harm the public health and were legal issues, rather than food safety issues. According to China's Supreme People's Court, 320 people were convicted of food safety crimes in 2011. The actual number might be higher than that, but such prosecutions show that law enforcement in China does place a high priority on food safety-related crimes [10].

In 2013, the new CFDA [22], which serves as a central authority, replaced the functions of many other regulatory bodies. This major overhaul signifies China's determination to build a high-level, unified system to handle food safety issues. However, with over 450,000 food production and processing companies (more than 350,000 are small enterprises with less than 10 employees), China's regulatory approaches are complicated and more difficult to implement than in most countries of the world. Government must take the initiative to assist and teach these small food processors about food standards and issue certificates to them after inspection of their operations.

On December 25, 2014, revision of the 2009 Chinese Food Safety Law was proposed and sent to the National People's Congress for review. On April 24, 2015, the revised Chinese Food Safety Law was passed to be implemented on October 1, 2015 [23]. The revised law is comprehensive and matches laws in the Western world. How long and how well the law can be implemented will be the key to future food safety in China.

The food industry (including production, processing, marketing, retail and food service industries) has the primary responsibility to provide safe food products for consumption.

China's agricultural production and food processing industries are unique in that they are dominated by small- and medium-sized farms and companies. Tracing back to the melamine issue, a *New York Times* reporter [24] visited Chinese villages and found that most Chinese farmers had two or three cows in their backyard. A milk collector, often on a bicycle, picked up the milk from the individual farmers and took it to the village collection station. No sanitation or refrigeration was used. By the time the refrigerated milk truck arrived at the village station and collected the milk, the microbial counts had reached a high level. The truck drivers often put a bottle of hydrogen peroxide into the milk to suppress the microbial count so as they can pass the food processing inspection. When asked why China allowed the individual farmers to keep the cows, the answer was that two or three cows may represent nearly half the income of the farmers. Therefore, changing the collection system would create a big social problem beyond food safety. The same situation applies to small food processing companies with less than 10 employees. Their profit margins are so low that they cannot spend money on safeguarding their products. The economical reality is such that the small farms are beginning to form cooperative operations, and small food processing companies are going through mergers to increase their size to gain economy of scale.

China's production industry needs to watch the excessive use of pesticides and antibiotics. The food processing industry needs to practice the now well-established, worldwide recognized Hazard Analysis and Critical Control Points (HACCP) system and its prerequisite programs [25]. Distribution and marketing industries must be careful to have proper temperature controls and sanitation conditions. The food service industry must work with local public health agencies to take on the huge responsibility of sanitation and serve safe foods to their consumers. In addition to the HACCP system, Leighton and Sperber [7] emphasized Good Agricultural Practices (GAP), Good Manufacturing Practices (GMP), Good Distribution Practices (GDP) and the new Good Consumer Practices (GCP).

Nevertheless, it may be quite a few years before China's production and food processing industries become similar to that of developed countries like the US or the UK. In many ways, China really does not need to mimic the system in developed countries. China should find methods to deal with food safety that is suitable for its own system. This will depend on innovations from Chinese scientists and business managers and just copying the same system as foreign countries.

On the other hand, large farms and food processing companies in China, which represent approximately 20% of the total production at the moment, have embraced *food safety* practices. They have new equipment and all the sanitation practices needed to produce safe foods. Dr. Chen Jemin, president of the Chinese Agriculture Industry Chamber of Commerce (CAICC) has been very vocal in promoting food safety. He often reminds audiences that safe foods are the result of production not inspection [26].

Lam *et al.* [10] suggested that assurance of food safety and rebuilding of public trust will need food industries in China to recognize that they are ultimately responsible and be held accountable for food safety problems. The Chinese food industries must adopt social responsibility as an overarching principle, putting food safety ahead of maximization of profits.

On the academic side, Chinese researchers in the food safety arena have enjoyed several years of rich funding sources from central and provincial government agencies and some food companies. Research results are submitted for publication in international journals. For example, *Food Control*, a high impact international journal devoted to the publication of food safety issues has seen submissions from China jump in recent years. Only six papers were submitted in 2006, but in 2010, 187 papers were submitted, leading to 575 papers being submitted in 2014 [27]. Unfortunately, most of the submitted papers from China were related to detection or determination of pesticides and harmful chemicals in ingredients and food products, aimed at use for inspection purposes. Furthermore, many papers used highly-priced equipment that is not practical for use in the real world. Some of the microbiology-related papers also tended toward working on the biochemical mechanism of the pathogens and lacked practical applications. The Chinese researchers really should work with industry personnel to find out the needs of industry and produce research results applicable to the commercial situation.

The Chinese universities have established many degree programs for food safety or food quality. There are no standard course requirements, rendering most of the graduates without the needed skills to work in the food safety field. There are few available food safety training courses for industry and government workers in food safety, except that offered by the Bor S. Luh Food Safety Research Center of Shanghai Jiao Tong University [28].

Chinese media has responded nicely to the needs of food safety reporting. The annual meetings between media reporters and scientists, arranged by Chinese Institute of Food Science and Technology since 2011 have paid big dividends. Every January, the major media reporters and 12 scientists get together to discuss the 12 major food safety events in the media from the past year [29]. The scientists each provide detailed analysis of one of the reported events and its relationship to food safety. They often point out that many reports are due to the lack of food safety knowledge by the general public and the media reporters. The reporters can ask very pointed questions to the scientists and get answers that they can understand. The reporters also establish contacts with scientists as resource people for future food safety reporting.

Recently, a book was published by Chinese reporters on how to properly report food safety issues [30]. Many of the major news media in China now have reporters who are responsible for reporting food safety-related news.

There is very little reporting on consumer behavior related to food safety in China. A 2009 report [31] by the Ministry of Health showed that more than half of the food poisoning problems reported in China were at home. They are not related to the production, processing or marketing part of the food consumption chain. Gong *et al.* [32] reported the handling of meat products at home in 15 Chinese cities. The results showed that most Chinese had no idea about safe handling of meats at home. Ignoring temperature and placing meats at room temperature for prolonged periods of time was the major problem. The authors suggested that consumer education is urgently needed to reduce food safety issues at home.

It can be said that present-day consumers in China are very confused, mainly due to widespread Internet messages. These messages often contain information without scientific background and the authors cannot be traced. To date, there is not a single authoritative website on food safety in China that consumers can trust.

1.5 The Future

Lam *et al.* [10] suggested that the Chinese government must strengthen the surveillance system and improve enforcement of food safety laws, increasing public awareness and improving transparency via media reporting, encouraging engagement of the public in discussion about and improvement of food safety. They felt that the future of food safety in China must emphasize responsibility, accountability and traceability. They suggested that a tracking system, so that the weak links in the protection of food safety can be identified, a regulatory system with a clear chain of command and division of labor among different regulatory bodies, adoption of common safety standards for all regulatory bodies and advancement of technologies to enable rapid and accurate measurement of food safety indicators, all have to be established.

Leighton and Sperber [6] proposed a new labeling system to aid consumers in identifying safe and high quality foods, copied from the EU system for electronic products. However, it may not work in foods. The original USDA meat grading system of prime, choice and standard has pretty much gone by the wayside.

The US CDC reports yearly on outbreak surveillance, and in 2014 there were 864 food safety incidents [33]. There were 13 246 illnesses, 712 hospitalizations, 21 deaths and 21 food recalls. Meat and fish products were the most common causes of food safety issues. Restaurants were the most commonly reported location, with 485 outbreaks. So, food safety problems occur everywhere in the world.

For China to continue to strengthen food safety concerns and gain back consumer trust, the government and industry must adopt transparency in their law and regulation process and food company operations. Transparency is the only way to gain trust from each other and to regain the trust of the consumers. In addition to transparency, science must be used as the basis for all information and communications.

One of the reasons that the US FSIS and FDA are very successful in their handling of the food safety laws and regulations is that they have very strong scientific research as their basis in their decision-making process. FSIS has the Agricultural Research Service (ARS), the world's largest agricultural and food research resource to consult with at all times. The FDA has many research staff at its headquarters in Maryland and at their various regional laboratories. The many federal agencies work together cooperatively and support each other. The website of food safety published by the USDA, FDA and CDC is a perfect example of the cooperation and coordination among these agencies [34].

One of the shortcomings of the CFDA is the lack of such scientific support. Without it, it is much harder for industry and consumers to believe in the guidelines issued and implemented by the CFDA.

Jen [35] felt that academia sets trends, meets challenges and recommends solutions to global food safety matters. The trend is to provide scientific facts about food safety to lead the government and industry down the right path. The challenges to academia are how to educate everyone about what is known and unknown about food safety, as well as providing sound recommendations based on scientific facts. One of the urgent needs of China is an authoritative voice from academia that can provide science-based information whenever a food safety event takes place. With several Chinese academicians in the food safety field, one possibility is for them to set up an information center for food safety.

There is also an urgent need for a standard curriculum of food safety to be set up by the Chinese Ministry of Education. Trained food safety graduates must be able to work in industrial environments and serve as qualified personnel at government agencies, including inspection services. Without qualified and properly trained personnel, it is not possible to improve overall food safety management in China. Thus, education and training programs must be greatly enhanced in China.

The Chinese media are on the right track in reporting food safety events. What is needed is a continued education system for new reporters who have no food safety background. Perhaps training courses specifically designed for reporters can be set up at creditable institutes for that purpose. Continued development of links between food safety media reporters and food safety expert scientists needs to be established. The media could consider working with academic scientists to develop a trustworthy website on food safety practices and information for consumers. Canada's CFIA has a great website called Fightback [36], which is used by many citizens of Canada to learn about food safety practices and news.

Chinese consumers are the weakest link of the five pillars of food safety in China. To bring the consumers along, the other four pillars of food safety have to have consumers in mind at all times as they plan and carry out their programs. On the other hand, consumers have to try to gain accurate sound scientific knowledge in food safety. The consumer should practice the food safety principles of cook, chill, separation and storage [37] at home to minimize food safety problems in the daily consumption of foods.

Besides transparency, education is a key factor. Transparency leads to trust. Education leads to cooperation. When all group members are well-educated in food safety principles and practices, total cooperation will follow, which will benefit everyone. When everyone works together, that is the road towards a food safety culture in China and the world.

References

1 Jen, J. (2016). Shared Responsibility of Food Safety. In *Food Safety in China: Past, Present and Future*. Ed. Jen, J. and Chen, J. China Science and Technology Press, Beijing, China. pp. 1–9. [in Chinese]

2 Chen, J. (2009). What can we learn from the 2008 Melamine crisis in China? *Biomedical and Environmental Sciences*, 22, 109–111.

3 China Food Safety Law. (2009). The 11th People's Congress, 7th Executive Meeting, Beijing, China. http://www.gov.cn/flfg/2009-02/28/content_1246367.htm [in Chinese] (accessed October 2016).

4 World Health Organization. (2010). 2010–2015 strategic plan. Geneva, Switzerland.

5 Jen, J. (2011). *Who is responsible for food safety? Presentation at the 1st International Forum on Food Safety*, Beijing, China.

6 Leighton, S. and Sperber, W.H. (2015). Consumers: Good consumer practices are necessary to further improve global food safety. *Food Safety Magazine*, April–May, 52–64.

7 United Nation Department of Economic and Social Affairs. (2011). World population prospects: the 2010 revision. Highlights and advance tables. New York, NY, USA.

8 Brown, L. (1995). *Who Will Feed China? Wake Up Call for a Small Planet*. W.W. Norton & Company, New York, NY, USA.

9 United Nations Food and Agricultural Organization. (2013). http://www.fao.org/corp/statistics/en/ (accessed June 2015).

10 Lam, H.-M, Remais, J, Fung, M.-C. *et al.* (2013). Food supply and food safety issues in China. *Lancet*, 381,2044–2053.

11 Liang, C.E., McDowell, S., Li, H. *et al.* (2012). Regional disparities are the burden of disease attributable to unsafe water and sanitation in China. *Bull. WHO*, 90, 578–587.

12 Chang, Y.F., Wen, J.-F., Cai, J.-F. *et al.* (2012). An investigation and pathological analysis of two fatal cases of cadmium poising. *Forensic Sci. Int.*, 220, e5–e8.

13 Zhang, Y.F., Jiang, F.B. and Ou, J.F. (2011). Global pesticide consumption and pollution with China as a focus. *Proc Int. Acad. Ecol. Environ. Sci.*, 1, 125–144.

14 Office of the UN Resident Coordinator in China. (2008). *UN in China, Occasional report: Advancing food safety in China*, Beijing, China.

15 2014 Food dollar: Industry Group (nominal) (2016). *USDA, Economic Research Service, Food Dollars Series data product*, Washington, DC USA.

16 Food and Drug Act. (1906). Public Law #59-384, 34 STAT.768. 21 U.S.C. Sec. I-15. US Congress, Washington, DC, USA.

17 Federal Food, Drug, and Cosmetic Act. (1938). 21. U.S.C. sec 329 (a) US Congress, Washington, DC, USA.

18 Nutritional Labeling and Education Act. (1990). US Congress, Washington, DC, USA.

19 FDA Food Safety Modernization Act. (2012). US Public Law 111-353. 21 U.S.C.2201.US Congress, Washington, DC, USA. https://www.gpo.gov/fdsys/pkg/PLAW-111publ353/pdf/PLAW-111publ353.pdf (accessed October 2016).

20 Li, C.H. (2009). Discussion of the pros and cons of the China Food Safety Law. *China Health Inspection Magazine* 546–551.

21 Han, Q. and Yuan, X.-G. (2010). The impact of the implementation of the law of the PRC on quality and safety of agricultural products on safe operation in wholesale market. 2010. *Economical Law*, 5, 64–67.

22 CFDA (2013) http://www.sda.gov.cn (accessed October 2016).

23 New China Food Safety Law (2015) http://www.gov.cn/zhengca/2015-04/25/content_2853643.htm (accessed October 2016).

24 Yardley, J.and Barboza, D. (2008). Despite warnings, China regulators failed to stop tainted milk. *New York Times*, September 26.

25 Sperber, W.H., Stevenson, K.E., Bernard, D.T. *et al.* (1998). The role of pre-requisite program in managing a HACCP system. *Dairy Food Environ. Sanitation*, 18, 418–423.

26 Chen, Z. (2015). Food industry responsibility in food safety. Presentation at the 6th International Forum of Food Safety, Beijing, China.

27 Malde, R. (2015). Food Control Publisher, Elsevier Publishing Inc., Oxford, UK. Private communication.

28 Yue, J. (2014). Food safety training courses in China. China International Food Safety and Quality Conference and Expo, session F, November 5–6, Shanghai, China.

29 Food Safety and Nutrition. (2014). Twelve media hot reports of food safety issues in 2013. *Chinese Institute of Food Science and Technology. February* 20, 2014, 11–35.

30 Jiang, S.J., Hu, H.C., Wu, L.L., *et al.* (2014). *Handbook of Reporting Food Safety Events*. People's Publishing Inc., Beijing, China.

31 Ministry of Agriculture. (2009). *China Agricultural Yearbook*. Chinese Agriculture Press, Beijing, China, p. 395.

32 Gong S.C. (2011). Food consumption behavior and food safety in the urban household of China. *Consumer Econ.*, 3, 80–84.

33 Deweg-Mattia, D., Manikonda, K. and Vieira, A. (2016) Surveillance for Foodborne Disease Outbreaks United States 2014: Annual Report, US Department of Health and Human Services, Atlanta, GA. http://www.cdc.gov/foodsafety/fdoss (accessed October 2016).

34 https://www.foodsafety.gov (accessed October 2016).

35 Jen, J.J. (2013). Global food safety trends, challenges and solutions. 3rd Asia Pacific International Conference on Food Safety, November 1–3, Taipei, Taiwan, Republic of China.

36 http://www.fightback.org (accessed October 2016).

37 USDA, Food Safety Inspection Service. (2007). Be Food Safe, four easy lessons in safe food handling. http://www.fsis.usda.gov/PDF/BFS_Brochure.pdf (accessed October 2016).

2

Overview of Food Safety Situation in China

Junshi Chen[1] *and Zhiqiang Zhang*[2]

[1] *China National Center for Food Safety Risk Assessment (CFSA), China*
[2] *Department of Food Safety Standards, Risk Surveillance and Assessment, National Health and Family Planning Commission, China*

2.1 Introduction

What is the food safety situation in China? The answers may vary depending on who answers the question. Most people would say the situation is “very bad, lots of problems”. A very popular response is a question: “What can we eat?” Most foreigners, including overseas Chinese, also believe that the food safety situation in China is “very bad” and “lots of foods are not safe”. However, these answers are based on perception, rather than on scientific assessment.

In order to accurately assess the food safety situation of any country, the first thing is to develop a set of scientific and objective methods and criteria for assessment. One should not forget history, because it is important to apply longitudinal comparison to the process of historical development of the so-called “good” or “bad”. Naturally, one cannot rule out comparison with other countries. No doubt, the key factor in deciding the national food safety situation is the level of food safety of the food business from farm to fork, namely “safe food depends on safe production”. The other important and indispensable factor is the comprehensiveness and capability of the government food regulatory control system. Of course there are other factors worth considering, such as science and technology, consumer awareness and knowledge of food safety.

Due to the limitations of information and available data, this chapter is not going to assess the complete food safety situation in China. We will use the compliance rate of food sampling and testing to partially reflect the food safety situation. As for assessing the comprehensiveness and capability of the government food regulatory control system in the past and present, the following recognized criteria were used, based on the numerous criteria mentioned in domestic and international publications:

- Whether the national food safety control system is sound and rational;
- Whether the national food safety standard is scientific, practical and has full coverage;
- The application of a risk analysis framework which comprises risk assessment, risk management and risk communication;

Food Safety in China: Science, Technology, Management and Regulation, First Edition.
Edited by Joseph J. Jen and Junshi Chen.

- The qualification inspectors and the process regulatory inspection; and
- The capacity of testing laboratories.

Due to space limitation, this chapter will not discuss each criterion separately, but instead will concentrate on how to carry out a comprehensive assessment using these criteria and include some appropriate examples.

2.2 The Past (1995–2009)

2.2.1 National Food Control System

In the last 10 years up to 2009, the national food safety control system of China has experienced a change from management by a few ministries to multiple ministries. According to the "Food Hygiene Law" (in trial) [1] in 1982, there were only two ministries in charge of food safety control. The Ministry of Health had the overall responsibility for food safety supervision and management, including imported food. The Ministry of Agriculture controlled primary agricultural products production (planting and breeding process). Starting from the early 1990s, after the promulgation of the "Product Quality Law" and "Anti-Unfair Competition Law", the General Administration of Quality Supervision, Inspection and Quarantine (AQSIQ) and the State Administration of Industry and Commerce (SAIC) also became involved in food safety control. At the same time, due to the institutional reform of the State Council, food import and export control responsibilities were moved from the Ministry of Health to the AQSIQ. Therefore, there were at least four ministries responsible for the food safety control at national level.

In 2004, in order to strengthen food safety control and streamline regulatory control responsibilities among ministries, the State Council decided that different ministries shared responsibilities for the different segments of the whole food chain, from farm to table. As a consequence, the Ministry of Agriculture was responsible for the control of primary agricultural production; the AQSIQ was responsible for food manufacturing and production; the SAIC was responsible for food distribution; the Ministry of Health was responsible for the inspection of restaurants and the canteens, and the State Food and Drug Administration (SFDA) was responsible for comprehensive food safety supervision, coordination among ministries and management of major food safety events [2]. Practice has proved that the split responsibility of the whole food chain has resulted in a situation such that "when there are no problems, every ministry is in charge; however, when there are problems, no ministry is in charge". In reality, the function of the comprehensive supervision and coordination of the SFDA never worked.

Obviously, there are lots of loopholes in this fragmented food control system and avoidable problems happened from time to time. A typical example was the case of about 300,000 infants having urinary stones after consuming melamine-tainted Sanlu infant formula in 2008. The police force and procurate team found that the numerous raw milk collection stations were the main place of milk adulteration, that is adding water and melamine into raw milk. However, as a very important part of the dairy value chain, the milk collection stations were neither regulated by the Ministry of Agriculture as a primary agricultural product nor regulated by the AQSIQ as part of the food production process. There was a vacuum gap within the dairy production chain. Eventually, the State Council decided that milk collection stations should be regulated by the agricultural sector, but this was too late to prevent the melamine event from taking place.

Because of segmented management, each of the responsible government agencies had their own inspection team from central to local level. The total number of food inspectors had reached hundreds of thousands, of which the industry and commerce sector (SAIC) had the largest number, followed by the health sector. The inspectors in the different government sectors had different qualifications, training and capabilities. They also implemented different standards (see the Section 2.1.2). More problematic was the repeat sampling and testing done by different inspection teams. In this situation, the supermarkets or food stores were often repeatedly inspected by the AQSIQ and SAIC inspectors, including sampling and testing. In many cases, different testing results (compliance or non-compliance) were announced by different inspection systems, which caused significant frustration in the food businesses.

2.2.2 Food Standards

In accordance with the "Food Hygiene Law" provisions, the national food hygiene standards were to be set by the Ministry of Health, but jointly issued by both Ministry of Health and the National Standards Commission under AQSIQ. After China joined the World Trade Organization (WTO) in 2001, it strengthened its participation in Codex Alimentarius Commission activities and used Codex standards as the main reference for the development of Chinese food standards. In no time, the structure of the Chinese food hygiene standard system became quite similar to that of the Codex system. The concept of risk assessment was introduced into the process of standard setting in China. In 2001–2002, the Ministry of Health organized a large group of experts to review and revise all of the nearly 200 standards that were in effect at the time. As a result, a new set of standards were jointly promulgated in 2003–2005 with the National Standards Commission and the Ministry of Health. Compared with the previous standards, the new ones merged similar standards and made them more applicable based on risk assessment, also making them consistent with Codex standards [3].

As of October 2008, the number of food hygiene standards had reached 454. Among them were eight categories of basic standards, including food contaminants, food additives, mycotoxins, pesticide residues, and packaging material additives. There were also 128 standards for specific food commodities and related products involving animal foods, plant foods, irradiated foods and disinfectants for food and beverage utensils and packaging materials. There were 275 official laboratory testing methods. Of those, 219 involved physical and chemical testing methods, 35 microbial testing methods and 21 toxicological testing methods and procedures. There were 22 food enterprise hygiene practices, including General Hygienic Practices for food production enterprises and Hygienic Practices and Good Manufacturing Practices for various categories of food companies. Finally, there were 19 food poisoning diagnostic criteria. All these standards formed a food hygiene standards system complemented by the Food Hygiene Law [4].

However, it should be recognized that in comparison with international standards and those of developed countries, the Chinese food hygiene standards did have shortcomings. For example, the application of risk assessment had just begun. The number of MRLs for pesticide residues in foods was inadequate, veterinary drug residues remained as the ministerial standards of the Ministry of Agriculture (not national standards), pathogenic bacteria criteria were qualitative (non-detectable), and product standards development was behind food industry development. More importantly, there were three national food standard systems effective at the same time, but based on different national laws and with different responsible ministries. In addition to previously described food hygiene standards promulgated by the Ministry of Health based on the Food Hygiene Law, there were also food quality standards circulated by the AQSIQ based on the Product Quality Law, as well as the agricultural products quality and safety standards from the Ministry of Agriculture based on the Agricultural Product Quality Safety Law. All three sets were national standards and most of them were mandatory and had hygiene indicators (e.g. total bacteria count) and safety indicators (e.g. limit for lead). However, these three sets of standards did not converge. In some cases, they contradicted each other. The biggest problem was that the boundary between hygiene standards and quality standards was unclear. Therefore, the government regulatory agencies, food industry organizations, food businesses and consumers were at a loss. In particular, this put the food industry in a very difficult situation [5].

For example, in the case of inorganic arsenic limit in foods, the Food Hygiene Standard (GB2762-2005) stated it was 0.05 mg/kg for poultry meat. However, according to the Food Quality Standard (GB16869-2005), it was 0.5 mg/kg for fresh and frozen poultry products, a difference of a factor of 10 between the two standards. Another example was the lead limit in foods. According to the Food Hygiene Standard (GB2762-2005), it was 0.2 mg/kg for meat and poultry. But according to the Agricultural Products Quality and Safety Standards (GB 18406.3-2001) it was 0.1 mg/kg for poultry and meat and according to Agricultural Industry Standards (NY/T5029-2008) it was 0.2 mg/kg for cooled meat. All these standards existed and were in effect at the same time [6]. One more example was gossypol in cottonseed oil. The limit was 0.2 g/kg in the Food Hygiene Standard (GB2716-2005), while it was 0.1 g/kg in the Agriculture Standards (NY 5306-2005). So, quite often the same product was qualified according to one national standard, but was unqualified based on another national standard. Food businesses were the major victims of these inconsistencies in food standards. By 2009, there were nearly 5000 food standards in China (see sections below for more detail).

2.2.3 Application of the Risk Analysis Framework

The risk analysis framework was promoted by the FAO/WHO to prevent and deal with any food safety problems. It has three parts, namely risk assessment, risk management and risk communication [7]. By 2009, China was still in the learning and initial application stage of the risk analysis framework. The obligation to follow the risk analysis framework was not mentioned in the Food Hygiene Law. It is worth mentioning that in 2000–2009, a nationwide food contamination monitoring network was established by the Ministry of Health and implemented by the Institute of Nutrition and Food Safety, Chinese Centre for Disease Control and Prevention. The Chemical Contaminants Monitoring Network (17 provinces, municipalities and autonomous regions), Microbial Pathogens Monitoring Network (22 provinces, municipalities and autonomous regions) and Food-borne Disease Surveillance Network (18 provinces, municipalities and autonomous regions), as well as the Chinese Total Diet Study (12 provinces, municipalities and autonomous regions) were all included in this network. Although these monitoring/

surveillance programs did not cover the entire country, they served as a solid foundation for the implementation of a national risk monitoring/surveillance program after 2009. In regard to risk assessment, China was just beginning to learn, and tried to apply the results of risk assessment in the development of food safety standards (e.g. contaminants limit in foods). In terms of risk management, only a few regulators, inspectors and representatives in food business learned about risk management and risk communication, let alone applied it.

2.3 Present (2009–2015)

2.3.1 National Food Control System

In 2009, the "Food Safety Law" was announced to replace the "Food Hygiene Law" and was implemented on June 1, 2009. A segmented national food control system was clearly identified in the new law.

Among the various ministries under the State Council, the Ministry of Health played a major role in the national food safety control system, with responsibilities for food safety comprehensive coordination, monitoring/surveillance, risk assessment, standards development and promulgation, information release, qualification recognition of food testing laboratories, development of laboratory testing regulations, and the investigation and management of major food safety incidents.

The whole food chain food safety control and inspection was divided into three segments: (1) AQSIQ responsible for food manufacturing, (2) SAIC for food distribution and (3) SFDA for restaurants and catering [8]. Under the new law, the fragmentation of food safety inspection activities intensified. More than ten ministries under the State Council were involved in food safety control, including health, agriculture, quality inspection, industry and commerce, food and drug, commerce and industry, information technology and public security.

The problem of the segmental management was fully shown in 2011 with the pig quarantine certificate issue from the pork clenbutanol incident of the Shuanghui Company. In order to reduce regulatory loopholes and delegate clear responsibility, the 2013 12th National People's Congress decided to make further reforms of the national food safety control system [9]. In addition to the Ministry of Agriculture's continuing responsibility for primary agricultural food products control, the newly established China Food and Drug Administration (CFDA) was given responsibility for the remaining parts of the whole food chain in manufacturing, transportation, storage, distribution and restaurants/catering. Because the CFDA also serves as the Standing Office of the Food Safety Commission of State Council, it also has responsibilities in policy formulation and planning, comprehensive coordination, handling of major incidents, and major information dissemination. The Ministry of Health (now the Health and Family Planning Commission) retained responsibility for risk monitoring/surveillance, risk assessment and standard development and promulgation. The SAIC was no longer responsible for food safety control, but was still responsible for food advertisement. The AQSIQ is only responsible for the inspection of import and export food and the control of food contact materials manufacturing. With fewer ministries involved in the national control system, the new system has the advantage of avoiding gaps within the entire food chain control. However, some experts felt that the reforms still had room for further improvements.

2.3.2 Food Standards

In order to solve the problem of multiple sets of national food standards which conflicted with each other, the Food Safety Law stipulated that only the national food safety standards (since Food Hygiene Law was changed to Food Safety Law, the food hygiene standards were named food safety standards accordingly) are mandatory. Other national or industry standards would not be. Beginning in 2009, the Ministry of Health (now the Health and Family Planning Commission) worked in collaboration with other ministries and related industry associations on the clean-up of approximately 4800 existing standards. They integrated them into around 400, according to the "Food Standards Clean Up Working Plan" and had three working principles: (1) to identify priorities, (2) to focus on standard system development and (3) to pay attention to science and practicability [10]. It was planned to have a goal of only one set of mandatory national food standards to be met according to the Food Safety Law by the end of 2015. The expectation was that the new food standard system will have about 1000 standards, divided into the following categories: general (horizontal) standards, commodity/product (vertical) standards, hygiene practices and laboratory testing methods [11].

During the process of the food standards clean up and integration, a number of new standards were also announced. As of April 2015, the Health and Family Planning Commission has issued 492 new standards – including horizontal standards – such as contaminants, mycotoxins, pesticide residues, food additives and nutritional fortifiers, and labelling requirements, such as the General Standards on Nutrition Labeling for Prepackaged Foods. Also issued were commodity/product standards, such as dairy, wine and food-related products (food contact materials, etc.), as well as hygiene practices and testing methods which covered more than 11,260 indicators including all raw materials for foods and processed foods and maximum limits for all the major hazards (chemical and biological) affecting food safety [11]. In the development of horizontal standards (e.g. food additives, contaminants, pathogenic bacteria, etc.), the completion of a number of priority risk assessment projects in recent years made it possible to use the results of risk assessment based on Chinese data as the scientific basis for standards development.

The three new standards concerning food for special medical purposes (FSMP) targeted at specific diseases or health conditions in specific subpopulations constituted a new standard category in the national food safety standards system. They are: Food for Special Medical Purposes (GB 29922 -2013), Food for Special Medical Purposes Intended for Infants (GB 25596-2010) and Good Manufacturing Practice for Food for Special Medical Purposes (GB 29923-2013). By referring to related Codex standards and corresponding standards in European Union and the USA, these standards were a first in China and clarified that foods for special medical purposes (FSMP) are foods which belong to the category of "foods for special dietary uses" and are also regulated under Food Safety Law. It is expected that the three FSMP standards will play important roles in the promotion of the proper use of FSMP in clinical medicine, improving nutrition support to meet the needs of patients. It also shows that the improvement of Chinese food standard system is more in line with international standards.

It is anticipated that, by the end of 2015, when the clean up and integration are completed, taking into account the new standards, the Chinese food standard system will be much improved and more advanced than the food standard system was in 2009. Using the new “Standards for Uses of Additives in Food Contact Materials and Products, GB9865-2016” as an example and in comparison with and the original standard “Hygienic Standards for Uses of Additives in Food Containers and Packaging Materials, GB 9685-2008”, it is clear that the new standards are more in line with the international standards and more practical in implementation. This includes: (1) the change of name from food packaging materials to food contact materials and products is in line with the current international name, (2) the introduction of the concept of specific total migration and add total specific migration limit (SML (T)) as an important indicator, (3) the number of permitted additives was increased from 958 to 1316, (4) four plasticizer and one printing ink substance were removed, based on the updated safety evaluation results and with reference to the standards of developed countries, (5) the scope of additive use was expanded to meet industry needs and (6) the use of six additives in food contact materials for infant and young child foods was restricted [12].

The major problems in the current food safety standards in China are: (1) the transformation of veterinary drug residues standards from Ministry of Agriculture regulations to national standards needs speed up, (2) the use of risk assessment results as the scientific basis for developing new standards and revising existing standards needs to be strengthened and (3) the laboratory testing method standards as mandatory standards is not conducive to the adaptation of advanced methods to improve existing methods.

2.3.3 Application of the Risk Analysis Framework

The implementation of Food Safety Law greatly promoted the application of the risk analysis framework. Progress is particularly evident in carrying out monitoring/surveillance and risk assessment work. Risk management work has somewhat improved, but the implementation of risk communication is still lacking.

It is stipulated in the Food Safety Law that “China shall establish a national food safety risk monitoring/surveillance systems to monitor food-borne illness, food contamination and harmful factors in foods”, to be organized and implemented by the Ministry of Health. Since 2010, the monitoring of chemical contaminants and pathogenic microorganisms in foods has been conducted annually, covering all 31 provinces, municipalities and autonomous regions in mainland China. In 2014, the number of monitoring sites increased to 2489, covering 86.8% of all counties. The food samples collected and tested covered 507 different foods in 29 food categories. A total of 286 chemical and microbiological indicators were tested and around three million data points were obtained annually. Meanwhile, the active surveillance of food-borne illness prevalence and etiology investigation have started, along with the strengthening of the food-borne illness reporting system. The number of sentinel hospitals for food-borne disease surveillance has reached 1965 (it will increase to 3363 by May 2015), which could serve as important resources for the identification of the causes of food-borne disease outbreaks. Furthermore, according to the needs of risk assessment and food standard setting, special monitoring projects were carried out from time to time (such as the phthalates contamination in foods in 2011, aluminium content in food in 2013–2014). It is believed that in chemical contaminants monitoring in food, China has caught up with North

American and European countries. However, in terms of food-borne diseases surveillance, China is still behind, particularly in disease burden estimation and etiology identification. During this period, a series of China Total Diet Studies was carried out as a useful complimentary activity to the national monitoring system.

The Food Safety Law also stipulates that "China shall establish a national food safety risk assessment system for biological, chemical and physical hazards in foods and food additives". By the end of 2009, the Ministry of Health, in accordance with the Food Safety Law requirements, established the first National Food Safety Risk Assessment Expert Committee. This group comprised of experts in medicine, agriculture, food, nutrition and other fields, with the National Centre for Food Safety Risk Assessment (CFSA) serving as the Secretariat of the Committee. In reference to international experience, a list of priority risk assessment projects was developed annually and experts were organized to implement the projects. So far, 13 planned projects have been completed for the assessment of chemical and microbiological hazards. Among them are the results of the dietary iodine risk assessment [13], dietary aluminium risk assessment [14], dietary intake of trans fatty acids [15], *Salmonella* in chicken meat, and *Listeria monocytogenes* in ready-to-eat foods. These have played important roles in the development of the corresponding food standards. However, it should be recognized that risk assessment activities have just begun in China. In terms of technology development and application of the results of risk assessment for use in risk management decisions, a large gap remains between developed countries and China. There is an urgent need to strengthen capacity building in this area.

In food safety control and inspection, the government has invested a lot of manpower, material resources and funds for annual sampling and testing of food samples up to several millions of primary agricultural products, as well as samples from manufacturing, distribution and restaurants/catering services. However, as compared with the risk-based control and inspection practice required by the risk analysis framework, there is still a huge gap and great efforts need to be made to change the current practice.

Risk communication is the weakest component of China's risk analysis framework. The efforts of the government and the industry in improving food safety in China are not generally recognized by consumers. There is a serious information gap between the media/consumer and government/academia, which has resulted in unnecessary overconcern by consumers and loss of confidence about the government. The main reasons are that the leading role of the government in risk communication is weak and ineffective, scientists do not want to face the media and exaggerated and untrue reports dominate the regular media and social media. The solution is to mobilize all stakeholders to actively participate in risk communication [16].

2.4 Major Food Safety Issues at Present

From the above, regarding the national control system, national food safety standards and the understanding and application of the risk analysis framework, it is obvious that the current (2009–2015) Chinese food safety regulatory system and capabilities are a significant improvement those in the past (1995–2009). However, there are still shortcomings in risk assessment, science-based risk management decisions and risk communication in comparison to developed countries.

As mentioned earlier in this chapter, the compliance rate of government food sampling/testing programs will be used as one of the indicators to assess the food safety situation in China. As we all know, there are many factors that could affect the compliance rate. For example, sampling and testing methods have been changed in different years, as have food category classifications and food standards. Therefore, it is difficult to accurately compare the compliance rate over the years. Nevertheless, the Chinese government has started continuous national sampling/testing programs since the late 1980s.[1] The annual number of food samples tested were as many as several hundred thousand or even several million. It is therefore possible to use these data to analyze the trend of the overall compliance rate over the past several decades as a reference to assess changes in the food safety situation in China. The total food compliance rate in the last 30 years in China has increased from 71.3% to 96.8% (see Figure 2.1). For some of the major and high-concern food categories, compliance rates were also significantly increased (see Figure 2.2). As of 2015, the compliance rates for meat (96.6%), poultry and products (96.9%), condiments, milk and dairy products (99.5%), aquatic and products (95.3 %), cereals and products (97.3%) and vegetable oils (98.1%) have improved respectively. The continuous and significant increase in compliance rates clearly show that the safety of the Chinese food supply in general has steadily improved. This is due to the efforts of the majority of food producers and traders, as well as the strengthening of regulatory control by the government.

When we assess these achievements, we should be aware that there are still many food safety problems in China and some of them are quite serious. From the adverse health effects point of view, food-borne illness is the most important food safety issue. According to the Daily Food Safety Information Report (12 March to 12 June, 2015) by the CFSA, there were 76 cases of food-borne disease outbreaks, 62 of which resulted in

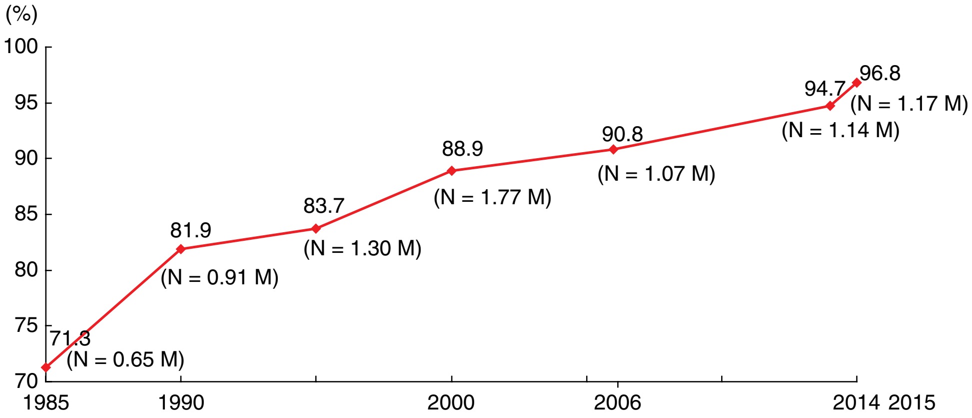


Figure 2.1 Changes in total food compliance rate in China (1985–2015) Note: numbers in brackets are sample numbers in millions. Source: data compiled by authors from references 17 and 18.

---

[1] National food sampling/testing programmes were implemented by different ministries in different years, i.e. 2006 and before, Ministry of Health; 2007-2012, AQSIQ and after 2013, China Food and Drug Administration [17,18].

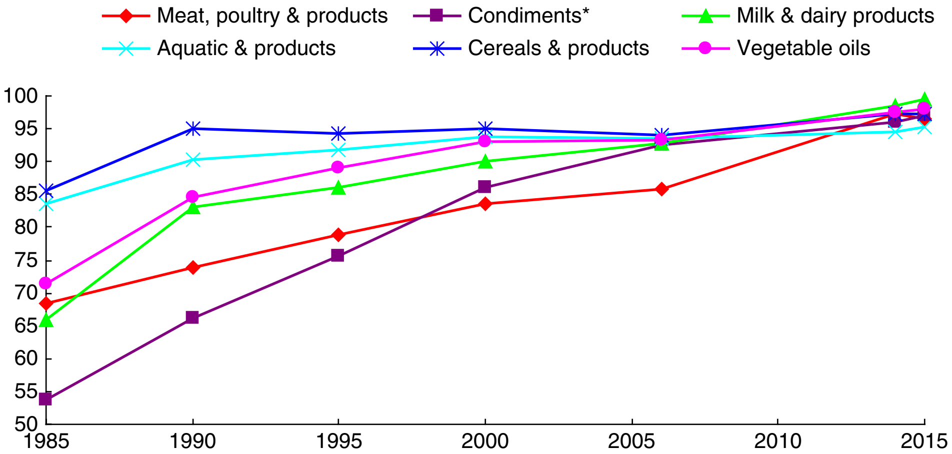


Figure 2.2 Changes in compliance rate of specific food categories (1985–2015) * Refer to compliance rate of soy sauce in 1985, 1990 and 1995. Source: data compiled by authors from references 17 and 18.

a total of 2064 patients and, among them, seven deaths. This will just be the "tip of the iceberg", because food-borne diseases are usually heavily under-reported in China. Currently, how many people out of the country's 1.3 billion people are affected by food-borne diseases every year is not clear.

In addition to the need to find out the prevalence of food-borne disease, it is necessary to carry out on-site epidemiological investigation and laboratory testing in order to determine the cause (food and pathogen) of food-borne disease. Only then can effective prevention and control of food-borne disease be possible. In recent years, the Health and Family Planning Commission has strengthened capacity building in food-borne disease investigation. Some initial achievements have been made in determining the etiology of food-borne disease events. For example, in late September 2013, 89 students from three schools in three separate districts of Beijing had fever, nausea, vomiting, abdominal pain and diarrhoea on the same days and were admitted to seven local hospitals. The Beijing Municipal Centre for Disease Prevention and Control (CDC) collected vomit, feces, anal swab samples and left-over food samples from the patients and carried out a pulsed-field gel electrophoresis (PFGE) molecular typing tracking analysis and traceability investigation. It was found that a cross-district *Salmonella enteritidis* outbreak was caused by chicken burgers manufactured by a company in Beijing using chicken meat from a company in the city of Dalian in the Liaoning province. However, this is only one of the very few outbreaks where the cause was found. The causes of most food-borne outbreaks remain unknown. The regular use of etiology investigation in sporadic food-borne disease cases has not started yet.

It should be clear that the institutional infrastructure and technical capability of etiological investigation of food-borne disease in China is far behind that of the developed countries. China holds a greater risk of food-borne disease compared to developed countries because of poor hygiene conditions in food production, processing, transportation, storage and distribution. Nevertheless, due to the small scale of food production and processing businesses, the impact of food-borne diseases could be less serious in China.

In terms of chemical contamination of food, the main issues are heavy metals (lead, cadmium) in grains and vegetables, mycotoxins in grains and nuts, illegal use of veterinary drugs in livestock and illegal use of pesticides in vegetables and tea. The main causes for these issues are environmental pollution, and small-scale and scattered farming (planting and breeding). The agricultural production unit is mainly up to 200 million individual farm households. As an example, the number of pig farmers in the Henan province alone is more than two million households. Although a small number of large dairy enterprises have their own dairy farms, the majority of small dairy farms have less than 10 cows. Taking into account the lack of scientific knowledge and law-abiding consciousness of the Chinese farmers as a whole, plus the sale of illegal high toxicity pesticides and veterinary drugs (e.g. clenbuterol) to the farmers by small illegal businesses, the occurrence of a small proportion of non-compliance events is inevitable at this current stage. Although the number of large food production and processing enterprises have increased rapidly in recent years and occupy most of the market share, the number of registered small- to medium-sized food manufacturers is greater than 400 000. Considering the large number of these low-qualification food enterprises and their pursuit of profit, among other factors, the frequency of use of inferior raw materials, of unstandardized production processes, of microbial contamination incidents and the misuse of food additives are somewhat unavoidable [19].

Currently, another major food safety problem in China is food adulteration or food fraud. The problem is worldwide, as indicated by the horse meat incident in Europe in 2013. From a professional perspective, food adulteration or fraud is not the same as food safety because the majority of adulterated foods (e.g., sugar adulterated honey, sulfur-treated chili pepper, adding yellow color to wheat flour to mimic corn flour) do not cause health problem to consumers. However, these economically motivated adulteration (EMA) events are currently quite common in China and they have seriously damaged consumer confidence in the food supply. The Chinese government has taken strong regulatory actions to control the use of non-food chemicals and illegal drugs. The National Health and Family Planning Commission has issued a list of "non-food substances that should not be added to food" (known as the blacklist) such as melamine, formaldehyde, Sudan red, malachite green and others; most of these substances could cause adverse health effects to consumers [20].

Consumers worry about food safety (food scares) because of the misunderstanding of food safety information. This is not unique in China. It is unrealistic to expect general consumers and experts to have the same level of knowledge and awareness of food safety information. However, in comparison with other countries, the misconception by Chinese consumers of food safety is more prominent. The Chinese consumers seem to believe untrue media rumors and news related to the safety of foods easily, but they are skeptical of scientific information. For example, although the government and scientists have carried out regular popular science education on food additives, consumers are still scared about any use of food additives. When they read about the news, blogs or micro-blogs such as "an ice cream contains 19 kinds of additives" or "long-term consumption of food additives may cause potential health hazards", they think it is the truth. Many consumers are still strongly against the use of food additives in food production. Therefore, in the analysis and discussion of food safety issues in China, we must take into account the psychological harm to consumers caused by misinformation and misconception.

2.5 Looking Forward

The Chinese government attaches great importance to food safety as one of the top priorities on its agenda. The set-up of the State Council Food Safety Commission is an obvious sign. National leaders make frequent remarks to convey the government's determination to control food safety in China [21,22]. Food safety in China is not only a public health issue, but a political issue related to social development and social stability. Due to the rapid development of the national economy and significant changes in people's living conditions, consumer demands for higher quality and safe food have also increased. However, it should be clear that China is still a developing country. The infrastructures of agriculture and the food industry with small-scale and non-standardized operations are still far behind those of more advanced countries. It will take a long time to scale up and standardize agriculture and food industry production in China. To resolve this conflict, China should make greater efforts to improve the food safety situation by learning from international experience and to strengthen risk communication, enabling consumers to rationally understand and deal with food safety problems that will continue to take place in the future.

In order to improve food quality and safety in China as soon as possible, two major efforts should be made. First, food producers and handlers should ensure food safety in the whole food chain from farm to table. It should be emphasized that within the whole food chain, the leading enterprises have a responsibility to help the upstream and downstream small- and medium-sized enterprises (SMEs) so that possible loopholes can be avoided. Second, the government regulatory agencies must strengthen cooperation among the different agencies to achieve integrated and seamless control of the whole food chain. Obviously, these two efforts are not able to be realized in a short time. However, if the strategic directions can be affirmed and moved forward steadily with continuous improvement of the "big environment" (e.g. development of the national economy, enhancement of science and technology, improvement of public knowledge), it is possible to make significant progress in a relatively short time. To this end, the following aspects should be emphasized:

- To further push the reform of the national food safety control system, aiming at further eliminating fragmentation, strengthening multi-sector coordination and cooperation, and creating synergy.
- To change the method of regulatory inspection from heavy reliance on end product sampling and testing to risk-based process inspection.
- To further improve and upgrade national food safety standards after the completion of cleaning, consolidation and integration of the existing standards in 2015. Some weak areas, such as veterinary drug residues and pathogens, need to be improved as soon as possible. When developing new standards and revising existing standards, the use of risk assessment findings as the scientific basis should be strengthened.
- To further improve and enhance the technical support for risk management decisions, in particular monitoring/surveillance and risk assessment. It is necessary to learn from advanced experience and technology to catch up with developed countries.
- To increase food safety investment by food industry, including human, financial and material resources. Large enterprises should set up an independent auditing system to compliment the traceability system to minimize food safety problems.

- To implement the above aspects, whether by the government or the food business, the no. 1 priority should be capacity building. Various forms of training through international exchanges and collaboration programs are highly encouraged.

2.6 Summary

Over the past 30 years, China – as a developing country with a huge population and large geographical heterogeneity – has made a big leap from a shortage of food to basically the elimination of hunger. However, there is an obvious conflict between traditional agriculture and farming and numerous small food businesses, and the increasingly stronger consumer demand for a safe, high-quality food supply. Both food producers and traders, and the government have a responsibility to meet consumer demands and ensure food safety. The only way to steadily improve the food safety situation in China is to follow the risk analysis framework by the joint efforts of all stakeholders. With the new Food Safety Law of 2015 put into place, it is believed that food safety in China will steadily improve.

References

1 The Standing Committee of the Eighth National People's Congress, People's Republic of China (30th October, 1995). Food Hygiene Law of the People's Republic of China. http://www.gov.cn/banshi/2005-08/01/content_18960.htm [in Chinese] (accessed October 2016).

2 General Office of the State Council (1st September, 2004). Decisions on Further Strengthening Food Safety. http://www.sda.gov.cn/WS01/CL0056/10755.html [in Chinese] (accessed October 2016).

3 Zhang ZQ. (2007). The food hygiene standards system in China. *Journal of Nutrition Support Professional Committee, Chinese Institute of Food Science and Technology.* 47–52 [in Chinese].

4 Fan YX, Zhu LH, Wang J, Zhang JB, Tian J, Mao XD, Chen YJ, Luo XY. (2009). Progress on food hygiene standards during thirty years of reform and opening up in China. *Chinese Journal of Food Hygiene.* 21(4): 312–315 [in Chinese].

5 Fan YX, Li XY. (2007). Status and challenge of Food Hygienic Standard System in China. *Chinese Journal of Food Hygiene.* 19(6): 505–508 [in Chinese].

6 ShaoY, Zhu LH, Wang J. (2001). A comparison of the General Standards for Contaminants in Food between China and Codex Alimentarius Commission. *Chinese Journal of Food Hygiene.* 23(3):277–281 [in Chinese].

7 FAO/WHO. (2006). *Food Safety Risk Analysis: A Guide for National Food Safety Authorities.* FAO Food and Nutrition Paper 87: 5–9.

8 The 11th Conference of Standing Committee of the National People's Congress, the People's Republic of China (28th February, 2009). Food Safety Law of People's Republic of China. http://www.gov.cn/flfg/2009-02/28/content_1246367.htm [in Chinese] (accessed October 2016).

9 The State Council (7th April, 2013). The main focused work of food safety in 2013 focus. http://www.gov.cn/zwgk/2013-04/16/content_2378952.htm [in Chinese] (accessed October 2016).

10 Fan Y, Peng R, Wang ZT. (2012). An analysis of the present situation of food safety standards system in China. *China Health Standard Management.* 3(9): 2–9 [in Chinese].

11 Wang ZT, Wang J. (2015). *Implementation and Application of Food Safety Standards.* China Zhijian Publishing House, Standards Press of China. ISBN978-7-5026-4093-4 [in Chinese].

12 National Health and Family Planning Commission of the People's Republic of China (20th January, 2015). National Food Safety Standards for Use of Additives in Food Contact Materials and Products (preparation illustrations). http://www.moh.gov.cn/zhuzhan/zqyj/201501/6ec37970b020464db13bd634b86f70e2.shtml [in Chinese] (accessed October 2016).

13 China National Expert Committee for Food Safety Risk Assessment (14th May, 2010). Salt Iodization and Risk Assessment of Iodine Status in Chinese Population. http://www.cfsa.net.cn/Article/News.aspx?id=F42C872C723F702EB11EF1606D5ECECC194E87C1BF57EA540B478BC77A7731D2195FEE09A7F31F1A [in Chinese] (accessed October 2016)

14 China National Expert Committee for Food Safety Risk Assessment (1st March, 2012). Risk Assessment of Dietary Exposure to Aluminium in Chinese Population. http://www.cfsa.net.cn/Article/News.aspx?id=D451A0282DBC8B2F0793BC071555E677EF79259692C58165 [in Chinese] (accessed October 2016).

15 China National Expert Committee for Food Safety Risk Assessment (19th December, 2012). Dietary Intake and Risk Assessment of Trans Fatty Acids in Chinese Population. http://www.cfsa.net.cn/Article/News.aspx?id=57BDA291C511BD8EA59546A6CDFAE1F724055CDF525A9AE57E2948C42FFB94F5C6423B2FC2E414C3 [in Chinese] (accessed October 2016).

16 FAO/WHO (2006). Food Safety Risk Analysis: A Guide for National Food Safety Authorities. *FAO Food and Nutrition Paper.* 87: 65–78.

17 *China Health Yearbook (1992–2007).* People's Medical Publishing House, Beijing [in Chinese].

18 China Food and Drug Administration food sampling and testing information. http://www.sda.gov.cn/WS01/CL1689/ [in Chinese] (accessed October 2016).

19 Chen JS. (28th February, 2015). To ensure food safety by industry self-regulation. Chen Junshi's guest talk at Xinhua website. http://www.xinhuanet.com/edu/xhhkt/20150228a/index.htm [in Chinese] (accessed October 2016).

20 General Office, National Health and Family Planning Commission. (18th September, 2014). List of Substances that May Be Illegally Added to Food (draft for comments). http://www.nhfpc.gov.cn/sps/s5853/201409/64a8d549311a432c8df6fb446fbfa8cc.shtml [in Chinese] (accessed October 2016).

21 Xi J. (24th December, 2013). Xi Jinping's talk at the Central Agriculture Working Conference. http://www.gov.cn/jrzg/2013-12/24/content_2553822.htm [in Chinese] (accessed October 2016).

22 Li K. (5th March, 2014). Government Report by Premier Li Keqiang at the 2nd Meeting of the 12th National People's Congress. http://www.gov.cn/guowuyuan/2014-03/05/content_2629550.htm [in Chinese] (accessed October 2016).

3

Food Safety Education and Training Programs in China

Yao-wen Huang

Department of Food Science and Technology, University of Georgia, USA

3.1 Introduction

Since 1978, China's economic reform program has brought over 30 years of economic growth. This has greatly increased food supply for its population, but has been accompanied by the wide-spread problems of low quality and unsafe food products. Due to the increasing incidence of food safety problems, the Chinese government has restructured its food regulatory agency and modernized its law and regulation on food safety control. However, it took 14 years to change the Food Hygiene Law (1995) to the Food Safety Law (2009), which meant changing the strategy from inspection of finished products to the prevention of root causes. In 2015, the 2009 version of the Law was further modified and passed by the Chinese Executive Committee at its 14th Meeting in April and came into force on October 1st of the same year.

This new Food Safety Law includes 10 chapters with 154 articles. Compared to the old version published in 2009, which had 104 articles, this law added 50 new articles, as well as a lot of revisions. It emphasizes the supervision and control of every step according to food safety-related issues. Manufacturer and government responsibilities and obligations are demonstrated. The punishment and obligations of other participants are also clearly shown.

According to the new Food Safety Law, Article 3 states that food producers or distributors shall have full- or part-time food safety technicians, food safety managers, and rules and systems for ensuring food safety. However, even before the issue of the 2009 edition of the Food Safety Law, the Chinese government had already required all food processing establishments to provide food safety professional positions. These require formal food safety education to be qualified for certification and workers are required to have training to ensure safe food production. Therefore, the food safety education and training programs in China have gained in importance through these evolving processes.

Food Safety in China: Science, Technology, Management and Regulation, First Edition.
Edited by Joseph J. Jen and Junshi Chen.

3.2 Definitions of Food Safety Problems

Food safety is a universal issue worldwide. It can be divided into the following categories: food safety, food defense, food fraud and/or food security. Each of these terms has their own definition. Before discussing food safety, a clear definition of each term needs to be understood.

Food safety is defined as the handling, preparation and storage of food in ways that ensure food products are not being unintentionally contaminated by any health hazardous substances in order to prevent food-borne illness. This includes a number of routines that should be followed to avoid potentially severe health hazards.

Although food defense also ensures safe foods to prevent harm to consumers, it is focused on the protection of food products from intentional contamination or adulteration by biological, chemical, physical, allergenic or radioactive agents. It addresses additional concerns, including construction, personnel and operational security. This is in contrast to food safety, which is based on accidental or environmental contamination. In addition, food defense also deals with prevention, protection, mitigation, response and recovery from intentional acts of adulteration by terrorists.

The definition of food security, however, is to ensure that all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food which meets their dietary needs and food preferences for an active and healthy life. As defined by the United Nations Food and Agriculture Organization (FAO), when people do not have adequate physical, social or economic access to food as defined above, it is called food insecurity. The term food security has at one time been misused as food defense right after the 911 terrorist attack in the United States in 2001. Nevertheless, some people define food safety as a qualitative safety while food security as a quantitative safety for an easier way to differentiate the two terms.

Food fraud is also a common unsafe food problem in developing countries. In China, people called this type of food product a “black-hearted food.” According to the definition of Spink and Moyer [1], it encompasses the deliberate and intentional substitution, addition, tampering or misrepresentation of food, food ingredients or food packaging; or false or misleading statements made about a product, for economic gain. The economic motivation behind food fraud is distinctly different from those for food safety, food defense and food quality. Food fraud is a broader term than either the economically motivated adulteration (EMA) defined by the Food and Drug Administration (FDA) or the more specific general concept of food counterfeiting [1]. The cause of an event might be food fraud, but if a public health threat becomes involved, the effect is an adulterated product and a food safety incident.

From the definitions of these terms, food safety deals with unintentional contamination and is an ongoing issue, while food defense describes an intentional contamination and is a spontaneous incident. In order to prevent health hazards and/or reduce the risk to an acceptable level, the cause and source of these issues need to be identified before taking any necessary measures.

Food fraud is obviously an intentional action. Although the results may only be for economic gain and not harmful to human health or the adulterants may also cause food-borne illness, the action has already caused damage to the food system, as well as to the confidence of the food markets.

In all, food safety, food defense, food security, and food fraud are under the umbrella of food protection. Only with the understanding of these issues can measures be effectively selected and implemented. Since China's economic reform, the food supply is no longer a problem of shortage. The unsafe food issues have been shifted from food security to food safety and food fraud.

3.3 Food Poisoning Incidents

Most food poisoning incidences can be traced back to one of the following major causes: biological, chemical and physical hazards, allergens or radioactive substances. Among them, pathogenic bacteria are the most important major cause. Although food fraud cases in China have always been the focus of media headlines, there are proportionally higher numbers of bacteria-caused cases. The reasons for the continued occurrence of food poisoning incidences in China can be categorized as subjective and objective factors.

3.3.1 Subjective Factors

3.3.1.1 Changes in Eating Habits

In recent years, the younger generation of Chinese consumers' eating habits have changed significantly, eating more raw and minimally-processed food. Yet, while microwave ovens have also been popularly used by households for food preparation, they have been known to cause uneven heating. Pathogenic bacteria, therefore, are the cause of food poisoning.

3.3.1.2 Changes in Family Structure

Chinese people are now living longer due to improved living standards and better health care systems. As the result of these changes, aging and immune-compromised populations are therefore increased. As people age, their immune systems and other organs may become compromised in recognizing and ridding the body of pathogens that cause food-borne illness. Many older adults have also been diagnosed with one or more chronic conditions, including diabetes, cancer and cardiovascular disease, and are taking at least one medication. The chronic disease process and/or the side effects of some medications may also weaken the immune system, which may make them more susceptible to many types of infections. In addition, the production of gastric acid decreases as people get older, making it more difficult for the host immune system to reduce the number of bacteria in the intestinal tract. All these factors increase the risk of illness.

3.3.1.3 Lack of Food Safety Knowledge

The majority of Chinese consumers lack food safety and sanitation knowledge and may ignore the necessary measures to keep food adequately prepared in their kitchen at home. Similarly, most consumers may not select the right place or food items for consumption when they eat out. Yet, many consumers gain their food safety knowledge from the media, which may provide biased or incorrect information. In addition, consumers' lack of knowledge on food laws, the right to know and business responsibility may also encourage the food industry to take risks regarding food fraud. Lacking food safety knowledge helps the occurrence of food-borne illness.

3.3.2 Objective Factors

3.3.2.2 Complexity of Supply Chain

Small- and medium-sized food producers play an important role in the supply chain of the Chinese food industry. Such producers in rural areas are difficult to regulate. Yet, up to 80% of the food industry in China is categorized as small- and medium-sized. In recent years, food products available in markets may be imported from countries around the world. A long and complex supply chain increases the risk of food safety problems. Advanced packaging techniques (especially vacuum or modified atmosphere packaging) increases the shelf life of food products, yet improper storage of these products, such as inadequate temperature regulation, may also increase the risk of these products becoming unsafe.

3.3.2.3 Drug Resistance of Bacteria

The bacteria that contaminate food can become resistant due to the abuse of antibiotics in humans and in food animals. Because of this link between antibiotic use in food-producing animals and the occurrence of antibiotic-resistant infections in humans, antibiotics that are medically important in treating infections in humans should not be used in food-producing animals to promote growth. Other factors, such as the abuse of sanitizer or pesticide applications in the environment may also increase the possibility of acquired mutations and/or drug resistance of bacteria. Drug resistant bacteria, such as *Salmonella* spp. and *Campylobacter* spp., are examples that may cause more cases of food-borne illness.

3.3.2.4 Correct Identification of Food Poisoning Cases

Compared to the past, when identification and reporting systems were lacking, the current availability of big data and the advancement of detection techniques ensure that food poisoning cases can be correctly reported and identified. This results in increasing records of food-borne illness which may have been ignored in the past.

From both subjective and objective factors, the food industry and consumers need to have more awareness of food safety, as well as what measures to take in order to prevent food-borne illness. Therefore, food safety education and training in China will be an important tool to accomplish our goals.

3.4 Food Safety Education and Training

According to the 2015 Food Safety Law of China, Article 44 of Chapter 4, Food Production and Business Operation, states that it is the duty of the management of the food industry to ensure that the staff are adequately educated and trained to perform their function effectively in production of a safe food [2].

The terms, “food safety education” and “food safety training” are often used interchangeably, but they have different meanings. Education is defined as the process of learning and acquiring knowledge through a formal setting such as in a degree or a professional diploma program, developing the ability to reason and judge a food-borne illness issue. It takes a longer period of time to completely change the current paradigm. Today, the bachelor degree in food quality and safety offered in colleges in China is a four-year education program.

Training, however, is defined as an organized activity aimed at imparting information and/or instructions to improve the trainee's performance or to help attain a required level of knowledge or skill for their jobs. This may occur in a shorter time frame, such as several days to a week or two. This training program aims to change trainees' behavior via hands-on practice. Training can be used as a tool for formal education, but a formal education program may not accomplish the purpose of training. Many colleges provide a variety of specific subject training programs through lifelong learning units to help job hunters pass the certification examinations in order to be qualified for certain positions.

Although food safety education and training are different, some trainers may use incorrect measures and tools for teaching. Incorrect teaching skills would lead to an ineffective training program. Many current training programs are therefore called "short courses" instead of "training workshops." The trainee completes whole courses, but is still not able to practically perform the job. The primary causes of the deficiency include either: (a) training materials not being well written or (b) trainers having no experience in the food industry.

The content of food safety education program should focus on the theory and principles of food safety issues, while the content of food safety training should focus on measures used to reduce the risk of food poisoning. Therefore, the strategy for teaching training courses should use both demonstration and hands-on techniques for a better result. Since understanding the concept and underlying practice is vitally important for implementation, both food safety education and food safety training programs are needed.

Changing the way employees do things (i.e. changing their behavior) is the key to effectively improving the food safety performance of a food business [3]. Food safety equals behavior; however, education and training is only one of a series of interactive components of a behavior-based food safety management system.

3.4.1 Food Safety Education

Establishing a better food safety education program is the basis for constructing an effective national food regulatory system; all personnel involved in food safety at different levels need to have formal food safety education. In order to establish a better food safety education system to effectively reduce food hazards, the government must do the following: form food safety education programs for different levels, including food safety education in the primary and secondary school curriculum, designing different educational contexts based on sections of supply chains, and promoting food safety education [4].

What is the context of food safety education? Wang *et al.* [5] stated that food safety education is "an activity that in sectors of food production, distribution, consumption, and monitoring, purposely leads those who have been involving the food safety affairs to accept food safety knowledge and to show behavior of obeying laws, in order to prohibit, control, and eliminate food contamination and hazardous factors that are dangerous to human health, preventing and reducing the occurrence of food-borne poisoning, ensuring food safety, protecting lives and health, increasing consumer's constitution." The definition also outlines the requirements of the food safety education.

3.4.1.1 Current Food Safety Programs in China

The system of food safety education started relatively late in China. In 2001, the Ministry of Education approved the first bachelor degree majoring in food quality and safety at Northwestern University. Due to the increasing awareness of food safety in recent years, many universities have added new programs to complement and meet these needs. By the end of 2014, there were 154 food quality and safety departments in Chinese universities. This newly established discipline is based on life science and food technology for students to study connections between nutritional quality, food safety and healthy aspects of food products. It is a curriculum that protects food nutrition and manages food safety, quality and sanitation.

Since students trained in this major have gained basic knowledge and skills in the field of food quality and safety, they are employable in the food industry, food analysis laboratories and governmental regulatory agencies, to work in production management, quality control, sales, food analysis, inspection, quarantine, evaluation and product development.

At the present time, the majority of food quality and safety majors in China are listed in agriculture, fisheries or forestry colleges. Mandatory courses include general biology, food microbiology, fundamental biochemistry, nutrition, food sanitation, food chemistry, food technology, quality control, food preservation, principles of food processing, food analysis techniques, food microbiology, functional foods, food toxicology, sensory evaluation, organic chemistry, inorganic chemistry, analytical chemistry, food experimental design, and food standards and laws. Elective courses include business management, food environmental science, food additives, food quality management, and so on.

Food safety is also related to public health and the safety of life, which has always been of utmost concern to all parties in our society. Huang reports that since college students are closely related to the food safety problem in their jobs or daily lives, integrating food safety knowledge into college physical education courses and health courses, with the further demand for developing and perfecting the supervision of food safety in China [6].

Although a food safety-related major is available in many colleges, a general course, such as a fundamental "Food Safety 101" is missing in higher education, so that most college students still do not have the opportunity to obtain food safety knowledge through classes. In order to ultimately reduce food safety or food fraud cases, it is an urgent task for the government to help establish a culture of food safety within the school system.

By looking at the current food quality and safety major in the university curriculum in China, there seem to be two pitfalls for the program. One is that mixed food quality-related courses with food safety courses in the program may dilute the importance of the food safety portion; the other one is that food processing and engineering courses are limited in the program. Since many food safety problems occur due to contamination during complicated production stages. Insufficient processing technology and engineering portions will mean that students do not quite understand how to produce a product, so that they will not be able to prevent, eliminate or reduce the food risk to an acceptable level during processing.

In order to correct these pitfalls, an ideal food safety education structure should be designed to have a food safety major as a Master's degree program instead of having this discipline in undergraduate programs. Only when undergraduate students have a solid foundation in food science, will food safety become an effective discipline.

3.4.1.2 Current Food Safety Education Programs in the US

The food regulatory system and food laws of the United States are some of the best in the world. Food safety education is included in the food safety system and is also an important link in all food protection. Education focuses on people who engage in food businesses as well as high-risk population [7].

The Institute of Food Technologists (IFT) accreditation program for the college food science curriculum should include the following four sections: food chemistry and analysis, food safety and microbiology, food processing and engineering, and skills and applied science. Food safety is part of the whole food science curriculum and is not separated as an independent major. The food safety major is established as a Masters degree program at the university.

Many major US universities offer food safety-related courses in the curriculum for food science and technology degrees. These courses include food safety control systems, Hazard Analysis and Critical Control Points (HACCP), toxicology, sanitation, and food laws and regulations.

However, several major universities, including Johns Hopkins University, the University of Arkansas, Utah State University, the Institute of Food Safety and Health, North Dakoda State University and Michigan State University, offer an advanced degree in food safety. Also, some other universities, including Iowa State University, Kansas State University, the University of Nebraska (Lincoln) and the University of Missouri (Columbia) formed a multi-state agricultural consortium to provide food safety and defense distance education as a Masters Certificate program. Let's review these programs:

Johns Hopkins University offers a Master of Science degree in food safety regulation. The program is designed to provide students with an understanding of the legal and regulatory complexities of food production, labeling and distribution. The required courses include introduction to food safety regulation, food microbiology, regulation of good food production practices, food labeling and packaging regulation, food toxicology, risk assessment and management, food safety audits and surveillance.

The University of Arkansas has an on-line Master of Science program in food safety. The program is administered by the Dale Bumpers College of Agricultural, Food and Life Sciences and is offered through the Global Campus, School of Continuing Education and Academic Outreach. The degree is a 30-hour, web-based, non-thesis degree. Major food safety related courses offered include food biosecurity, food-borne diseases, safety and sanitation for the food industry, food toxicology and contaminants, food safety laws and principles of epidemiology.

Utah State University offers a Master of Food Safety and Quality (MFSQ) degree, which is a professional degree designed to provide students with in-depth training in food safety assurance. It also trains students in the use of management systems that address food safety through the analysis and control of biological, chemical and physical hazards from raw material production, procurement and handling, and manufacturing, distribution and consumption of the finished product. While this is not an on-line program, some food safety-related core courses, including principles of food sanitation and principles of food toxicology are offered on-line; others, such as food safety and quality, food laws and regulations are face-to-face courses.

The Institute of Food Safety and Health (IFSH) offers a Masters degree program in food safety and technology (FST) designed to educate food technologists and engineers in aspects relating to food processing and safety. Students can specialize in food processing and packaging, food microbiology and safety, compositional safety of food (chemistry) and food for health (nutrition). Graduates of the program will be prepared to assume responsible positions in food manufacturing operations, research and development, food safety, compliance and regulatory affairs, and quality assurance, in the processing, retail and food service sectors of the food industry.

North Dakota State University offers undergraduate, MSc, and PhD programs in two areas, food safety and microbiology. In addition to undergraduates, food safety program admission is also open to all qualified graduates of universities and colleges of recognized standing. Appropriate degrees might be in food science, food safety, meat science, cereal science, microbiology, veterinary science, economics, engineering, dietetics, nutrition, agricultural policies or communication. The food safety program is, by design, highly flexible to allow study in the diverse areas of specialization that are related to food safety. Food safety-related courses include food safety information and flow of food, food-borne hazards, food safety risk assessment, epidemiology of food-borne illness, costs of food safety, food safety crisis communication, food safety risk management, food safety regulatory issues, food safety risk communication and education, food laws and regulations, food safety practicum, food toxicology, advanced crisis communication and risk communication.

Michigan State University offers an on-line MSc in Food Safety program, designed for mid-career food safety professionals who want an advanced degree, but are unable to leave their jobs to attend classes on a university campus. Five core courses (total of 15 credits) include introduction to food safety and professional development, evolution and ecology of food-borne pathogens, food safety toxicology, food-borne disease epidemiology, international food laws and regulations or US food laws and regulations. As an alternative to the Master of Science degree, the MSU also offers a four-course (12 credit-hour) on-line Certificate in Food Safety, which is achieved through Lifelong Education.

The other MSU food safety-related program is the food fraud program, which was originally started as a food safety course within the subject of the packing in the on-line Professional Master of Science in Food Safety program. This program merged with other areas, including the food defense graduate course and the Packaging for Product Protection Initiative (P-FAPP). The anti-counterfeit and product protection graduate course was first offered in the summer semester of 2008. The graduate courses offered include anti-counterfeit and product protection, packaging for food safety, quantifying food risk, global food safety, food protection and defense.

In addition to the above degree program, there are two other graduate certificate programs. Iowa State University, Kansas State University, the University of Nebraska (Lincoln) and the University of Missouri (Columbia) provide food safety and defense distance education courses and have established a multi-state agricultural consortium to develop and deliver high-priority collaborative distance education programs in the food and agricultural sciences. This certificate program prepares graduate students and food-related professionals to effectively deal with food safety and biosecurity issues.

The major courses offered include a multidisciplinary overview of food safety and security (2 credit hours), Kansas State University, HACCP (2 credit hours), Kansas State University, food-borne toxicants (2 credit hours), Iowa State University, food laws and the regulatory process (2 credit hours) Iowa State University, risk assessment for food, agriculture, and veterinary medicine (3 credit hours) Iowa State University, rapid methods and automation in microbiology (2 credit hours), Kansas State University.

The distance education Food Safety and Security Certificate program serves the needs of industry and agencies that must protect the human food supply from accidental or deliberate contamination with pathogenic microbes and/or toxicants. In an era of terrorism and global food systems, effective control of food-borne hazards requires advanced education.

The other food safety certificate program is offered by University of Minnesota (Twin City). The program is listed within the School of Public Health and not in the food science program.

3.4.2 Food Safety Training

China announced its new Food Safety Law on April 25, 2015, while it was implemented on October 1. The understanding of the law by regulatory agents as well as the food industry has become a timely task. To have a better food safety training system for food business, a policy of "training before working" by government has therefore been implemented to reinforce that food producers and processors should be responsible for safe food. On December 9, 2015, the Chinese Food and Drug Administration (CFDA) released the "Draft Implementing Rules for the Food Safety Law" for public comments before January 9, 2016. The document contains 200 Articles. Among these Articles, Article 150 states that the food and drug administrative department and other departments under the State Council are responsible for making the training syllabus, and the food and drug administrative department and other departments under the People's Governments of provinces, autonomous regions and municipalities are responsible for organizing examination. A law enforcement officer for the food and drug administrative department and other departments shall take no less than 40 hours of food safety professional training every year and take an examination. Those failing the examination shall not be engaged in enforcement of food safety law.

Based on this document, the food regulatory agencies at different levels in the government needs to take the lead for training food producers in the areas of food laws and food safety practices within their jurisdiction. According to the new Chinese Food Safety Law, a certified food safety manager has been created for all jobs in food regulatory agencies.

3.4.2.1 Current Food Safety Training Programs in China

The current most popular certification training programs for food safety include the following:

1) *Hazard Analysis and Critical Control Points (HACCP)*
   Based on the Codex Alimentarius Commission CAC/RCP 1-1969, Rev. 3 (1997), China's State Commission on Supervision of Certification in 2002 issued regulations on "Hazard Analysis and Critical Control Point (HACCP) System and Guidelines for its Application" requiring the HACCP certification for six categories of export food manufacture. As a scientific and systemic method, it is applied in the process from primary manufacture to ultimate consumption, and it ensures the safety of food through confirming and estimating specific harm and measures of control. HACCP emphasizes prevention rather than the testing of final products. It has high

economic and social benefits and is considered to be the most effective way to control diseases caused by food.

Since the first HACCP training for the seafood industry was held in Tsindao by the National Seafood Quality Inspection Center (NSQIC), with support from the FAO and Ministry of Agriculture (MOA), in March 1993, more training courses have been organized. In addition to government run training courses, many universities, including Shanghai Jiao Tong University Bor S. Luh Food Safety Research Center have been teaching a basic level course, as well as train-the-trainer classes under the accreditation of International HACCP Alliance (AHI) and Grocery Manufacturers Association (GMA).

2) *Green Food Certification*

In 1990, China's MOA created the Green Food program. The China Green Food Development Centre (CGFDC) under the control of the MOA was founded in 1992, to be responsible for national development and management of Green Food. The CGFDC is responsible for certification and owns the Green Food logo by developing and maintaining the Green Food standard, coordinating inspections and monitoring, and drawing income from certification fees.

The CGFDC subsequently split Green Food certification into two grades, Grade A and Grade AA, in the late 1990s. This strategy recognized that Green Food lays very good foundations for the development of organic food. In 2005 the first Chinese national organic standard was issued by China's Environmental Protection Agency (SEPA). Green Food Grade AA now excludes synthetic pesticides and fertilizers, and is harmonized with China's national organic standard, as well as international organic standards. Green Food provides farmers with a stepped path from chemical farming to green eco-certified farming, as well as a pathway onward to organic certification. These developments have facilitated the rapid adoption of organic agriculture in China.

3) *Quality and Safety Mark*

The Quality and Safety Mark (formally the Industrial Product Manufacturing License) was introduced in 2003. It is a mark for food, beverages and other products. The mark is managed by the General Administration of Quality Supervision, Inspection and Quarantine (AQSIQ). The license is required for many product categories if they are both manufactured and sold in China. High risk products such as food and beverages will have more stringent regulations applied, and additional implementation rule; it should also be noted that at the provincial level other requirements may also apply. This is particularly the case for food production, where local authorities often stipulate specific requirements relevant to the local conditions and geographical location.

As of 2001, the market access system for food quality and safety was first announced in five categories of food, including rice, flour, oil, sauce and vinegar. In 2003, foods in these categories with a Food Production License, but not printed with the food market access mark were not allowed to be sold. Later in the same year, the range expanded to include meat products, dairy products, beverages, condiments (such as sugar and MSG), instant noodles, biscuits, iced beverages, instant rice and flour foods, and rising foods, and so on.

4) *Certified Food Safety Professional*

   According to the 2009 version of the Food Safety Law (FSL), "An enterprise engaging in the production or business operation of food shall establish and improve its food safety management system, strengthen the training of its employees in respect to food safety knowledge, be provided with full-time or part-time food safety managers, do a good job in inspecting the food which it produces or operates, and carry out food production and business operation activities according to law." In 2006, the Food Safety Professional certification examination was first held and has been routine since. Not just the FSL, but also the Ministry of State's "Outlines of Food Safety Education Promotion" are the basis for requiring the training program for a Food Safety Professional.

   The above certifications are required by laws and regulations, and the training programs were popular in China. This is true everywhere, because businesses will have an incentive to encourage or pay for their employees to take training courses so that they will fulfill the requirements to get their business accredited.

3.4.2.2 Current Food Safety Training Programs in the US

The following training subjects are currently offered:

1) *Good Manufacturing Practices (GMP)*

   The Current Food Good Manufacturing Practices (cGMPs) describe the methods, equipment, facilities and controls for producing processed food. As the minimum sanitary and processing requirements for producing safe and wholesome food, they are an important part of regulatory control over the safety of the nation's food supply. The cGMPs also serve as one basis for US FDA inspections.

   The cGMPs are the result of an extended rulemaking process that spanned decades. They consist of seven subparts, two of which are reserved. The requirements are purposefully general to allow individual variation by manufacturers to implement the requirements in a manner that best suits their needs. The cGMPs have also been modified under the 2011 Food Safety Modernization Act. Along with SSOP, they are the pre-requisites of an effective HACCP system. Training programs for cGMPs have been always held with HACCP training.

2) *Better Process Control School (BPCS)*

   The BPCS subject areas include thermal processing system operations, microbiological food safety, equipment operations, and acidification and container closure evaluation programs for low acid and acidified canned foods (LACFs).

   In 1979, the FDA regulations in 21 CFR 108, 113 and 114 became effective. It requires that each processor of low-acid or acidified foods operates with a certified supervisor on hand at all times during processing. These regulations are designed to prevent public health problems in LACFs. The US Department of Agriculture's (USDA) Food Safety and Inspection Service (FSIS) regulations 9 CFR 318.300 and 381.300 also required thermally processed meat and poultry products to implement this sytem in 1987.

   Due to increasing low acid canned food imports, the USFDA has also required a certificate of BSPC for the Chinese LACF export industry. Although no official classes are offered yet, the Shanghai Jiao Tong University Bor S. Luh Food Safety Research Center has been officially accredited by the GMA to offer classes in 2017.

3) *Global Food Safety Initiative (GFSI)*

   The Global Food Safety Initiative (GFSI) is an industry-driven initiative providing thought leadership and guidance on food safety management systems necessary for safety along the supply chain. This is accomplished through collaboration between the world's leading food safety experts from retail, manufacturing and food service companies, as well as international organizations, governments, academia and service providers to the global food industry.

   GFSI is not a scheme in itself and does not carry out any accreditation or certification activities. It has developed to become more than a benchmarking organization and the status of recognition is achieved through a comprehensive benchmarking process.

   The guidance document for GFSI is regularly revised to reflect improvements in best practices. GFSI has recognized a number of food safety management schemes that fulfill the criteria of the GFSI guidance document. Once a standard has gained formal recognition by the GFSI board of directors, this standard is deemed to meet all of the requirements in the guidance document. Certification according to a GFSI-recognized scheme can be achieved through a successful third party audit against any of the following schemes recognized by the GFSI: BRC Global Standard for Food Safety (Seventh Edition); Canada GAP (Canadian Horticultural Council On-Farm Food Safety Program); FSSC 22000 Food Products; Global Aquaculture Alliance Seafood Processing Standard; GLOBALG.A.P.; Global Red Meat Standard (GRMS); IFS Food Version 6; PrimusGFS; Safe Quality Food; and China HACCP.

   Currently, GFSI Benchmarking primary- and middle-level training programs have been taught in China. Some of the recognized schemes have also been offered by different foreign companies.

4) *Preventive Controls for Human Foods Certification*

   This workshop provides the credentials to meet US FDA requirements for development and implementation of HACCP-based systems as part of the Food Safety Modernization Act (FSMA) regulations and to be recognized as a Preventive Controls Qualified Individual. The Preventive Controls Rules require that each facility, including exporting foreign companies have Qualified Preventive Control Individuals for the development and implementation of Hazard Analysis and Risk-based Preventive Controls for Human Foods.

   This course was developed by the Food Safety Preventive Controls Alliance, a broad-based public private alliance created by the US FDA, and the Illinois Institute of Technology's Institute for Food Safety and Health (IFSH) in cooperation with the Association of Food and Drug Officials (AFDOs). The curriculum is designed for food industry professionals with responsibility for a company's Food Safety Plan in terms of development, implementation or maintenance of food safety activities. It is suitable for those working in any area of the facility where preventive controls will be used (quality, sanitation, operations, logistics, maintenance, etc.), or where knowledge of the rules will be helpful (sales, marketing, upper management).

In all, due to the increasing numbers of international joint ventures for the food industry in China, companies offering international training programs have been booming. Food companies are willing to pay for their employees to participate. These training courses have recently been gaining popularity in China.

3.5 Summary

To reduce food-borne illness risk, food safety education and training programs are vital for success. Food safety education and training are also an effective measure to help establish a culture of food safety for the industry. Although training can be treated as education, the education cannot replace the training.

The objective of training is to teach practical skills needed for implementation, while that of education is to teach both theory and implementation. Since the trainees may have different educational backgrounds, as well as professional experience, to become a super trainer one needs to be not only an expert in teaching the subject matter, but also to be knowledgeable about many related things.

As the improvement of food safety has been the most urgent and timely task for the Chinese government, adequate education and training materials with the right instructors are vital for a successful program to help implement the 2015 Food Safety Law.

References

1 Spink, J. and Moyer, D.C. 2011. Backgrounder: Defining the public health threat of food fraud. http://foodfraud.msu.edu/wp-content/uploads/2014/07/food-fraud-ffg-backgrounder-v11-Final.pdf (accessed October2016).

2 Standing Committee of the National People's Congress. 2015. Food Safety Law of the People's Republic of China [Revised].

3 Yiannas, F. 2009. *Food Safety Culture: Creating a Behavior-Based Food Safety Management System*. Springer-Verlag, New York, 95 pp.

4 Cao, Y. 2014. Food Safety Education System. *Journal of the Shandong Police College.* 26(5): 95–99 [in Chinese].

5 Wang, S., Du, B. and Zhang, C. 2010. The exploration on Chinese food safety education. *Chinese Food and Nutrition.* 146: 17–20 [in Chinese].

6 Huang, A. 2015. Research on knowledge of food safety into the curriculum of physical education and health. *Advanced Journal of Food Science and Technology* 8(7): 488–491.

7 Li, S. 2006. American food safety education system and its characteristics. *Chinese Food and Nutrition* (11): 11–14 [in Chinese].

4

Development of the Food Industry in China

Suhe Meng[1] *and Joseph J. Jen*[2]

[1] *Chinese Institute of Food Science and Technology, China*
[2] *California Polytechnic State University, USA*

4.1 Introduction

Food industry development is an important economic cornerstone in China. It produces basic necessity goods for consumption by consumers. According to the Chinese industrial categories, the food industry in China consists of four major categories: (a) agricultural processing products, (b) food manufacturing products, (c) wines, beverages and teas, and (d) tobacco. These four major categories can be further divided into 22 medium categories and 56 minor categories [1].

For 2014, under an unfavorable domestic and global economy, the Chinese food industry still managed to obtain an impressive 8% growth rate, which was slightly lower than the 8.5% growth of the national GDP [2]. However, this was the third year in a row that the Chinese food industry growth rate declined in comparison with the previous year. It can be said that the food industry is facing a major challenge and must transform itself from the previous "end product price war" era into the "brand name establishment and new innovation" era. Food safety is playing an important role in this transformation.

4.2 Background Information

Although from a global perspective the food industry is a mature enterprise, the development of the food industry in China has had a short history. It had gone through a high-speed development that matched the fast economic growth of the nation. For 1998, the total gross production value of the industry was at 5780 million Chinese Yuan. By 2014, the value had increased to 10.89 trillion Chinese Yuan, an 18.84-fold increase for the 16-year period [2]. Since the middle of the 1980s, the industry has maintained an annual growth rate of 15–20% from the previous year. That was the golden age of the Chinese food industry. The industry development followed the fast growth of all segments of society, and can be separated into three major stages: the "food security" stage

Food Safety in China: Science, Technology, Management and Regulation, First Edition.
Edited by Joseph J. Jen and Junshi Chen.

Table 4.1 Food processing industry development in China (1998–2014).

Historical development	1998	2008	2014
Per capita income	US$791	US$3000	US$7485
Total food processing industry value	US$942 billion	US$6.5 trillion	US$17.429 trillion
Development stages	Ingredient expansion period	Industry transformation period	Efficiency and ecology development period
Specifications	Food security stage	Better quality stage	Healthy food stage
Market directions	Equal export and import	Mostly import	Value-added trend
Industry role in society	Increased value for agricultural products to support farmers	Satisfy consumer desire for high quality food products	Supply safe, nutritious and healthy food products

in 1998, to the "better quality food" stage of 2008, to the "healthy food" stage of 2014 with the characteristics of the stages shown in Table 4.1 and Figure 4.1.

During these transition periods, the food industry played the role of first supporting the farmers to satisfy consumer demands in the food security stage, and second providing higher living standards to consumers in the better quality stage and finally, assuring

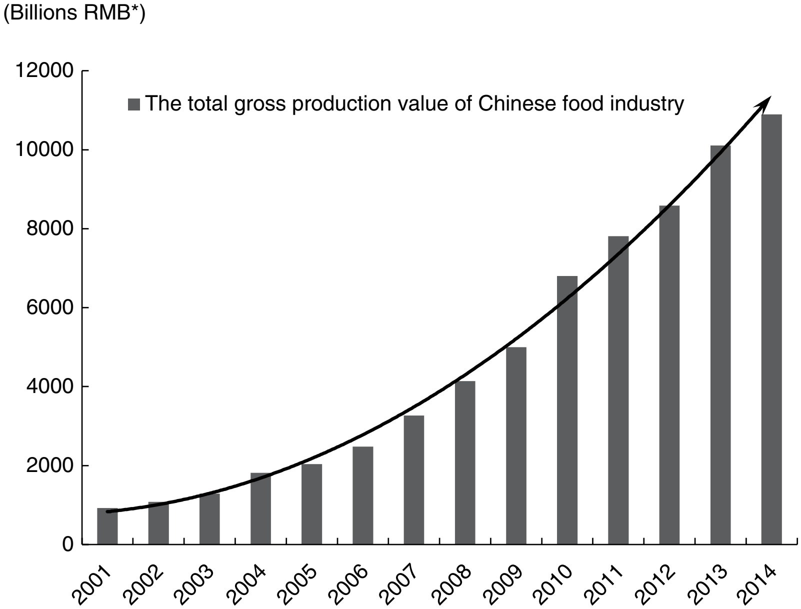


Figure 4.1 The total gross production value of Chinese food industry from 2001 to 2014. RMB*= Chinese Yuan.

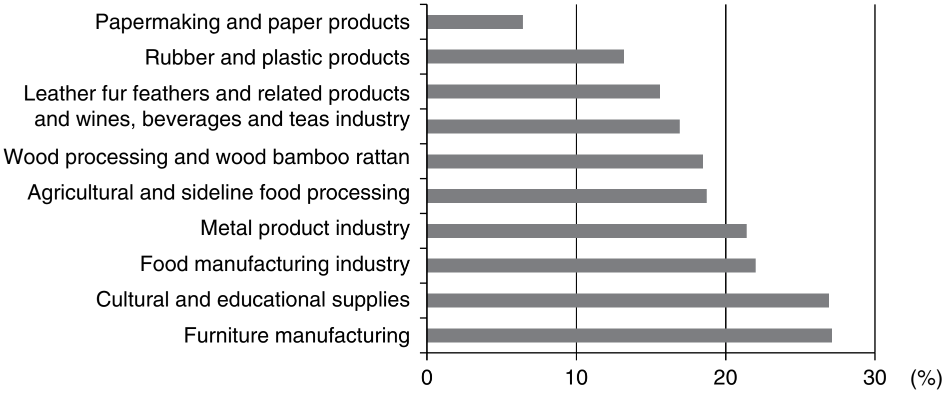


Figure 4.2 The investment rate of major industries of Chinese light industry in 2014 [3].

food safety and providing consumers with nutritious and healthy food products, while at the same time being ecologically friendly in the healthy food stage.

With the per capita income growth, the food industry has changed with multiple ingredient sourcing and expansion into a more efficient and innovative enterprise. With the awareness of food safety and healthy food needs, Chinese consumers are watching the value-added development of the food industry. People have changed from needing enough food to avoid hunger, to desiring high-quality foods, to demanding safe, nutritious and healthy foods. Many consumers are starting to notice the brand names, while at the same time are still price sensitive. The consumer needs are forcing the food industry into innovative and value-conscious new products. The food industry also changed from ingredient sourcing from domestic origins to global sourcing, with imports playing an ever increasing role in new products. The investment rate of the food industry remains at high levels among all light industry categories in China, as shown in Figure 4.2 [3]. It can be said that the food industry remains an active and viable industry in China, now and for many years to come.

4.3 Current Status

4.3.1 Internal Structure Changes in the Food Industry

For the moment, the Chinese food industry is in a complicated situation. It is facing four major changing factors: PEST, which stands for policy, economics, society and technology (Table 4.2).

From the policy side, the government is pushing for domestic consumption instead of export. New financial policies mean tight funding controls. New food products need new ingredients, many of which have to be imported from other countries, thus requiring a loosening of import policies. Most significantly, the government realizes the importance of food safety and is developing new regulations and tightening inspections.

From the economic side, Chinese economic development is moving into a slower growth era. Consumer disposable income is rising every year. Transportation

Table 4.2 Production environments of Chinese food industry in 2014.

Policy	Expanding domestic demand, intensifying food safety inspection, tightening financial system, multiple sourcing and loosening import of food ingredients
Economy	Moving into the moderate speed development stage, transforming the traditional foods into nutritious and healthy foods, recognizing the consumer disposable income rise, quick transportation of goods, push for city–country integration
Society	Focus on food safety and healthy foods with convenience and multiple choices, notice the aging population, end of one child policy and singles, food marketing opportunities, business awareness of goodwill activities, the beginning of food safety science education
Technology	Rapid development of food safety technology, traceability of food production origin and alert system, analysis of pesticides and veterinary drug residues in foods, low sodium and low fat technology, energy saving, less pollution and other environmental technology

construction makes the transportation of food products easy and cost effective. Many varieties of foods are available in every corner of the country, not just in the big cities, as in the past. Consumer demand for healthy and safe food products will continue to grow.

From the society side, the end of the one-child policy, an aging population and single-parent families have all led to consumer awareness and demand for a great variety of foods, all of which need to be nutritious and healthy, as well as being safe. This brings new opportunities for food industry development into niche markets, specialty products and marketing activities. Following the development of public knowledge of food safety and nutrition, the food industry is beginning to participate in goodwill public relations activities.

From the technology side, new methods related to food safety are developing fast, particularly for inspection purposes. Traceability technology, and pesticide and antibiotic analyses are leading to control of food safety from farm to table. Public interest in low sodium, low fats and oils, and functional foods all provide food industry with new products to develop. Green environmental concerns also lead to the marketing of foods that do not contaminate the environment.

At the same time, the distribution of the food industry within the nation is no longer limited to the coastal regions. The eastern region now contains 42.11%, the middle region 26.81%, the western region 18.89%, while the northeast contains 12.19% of the food companies [4]. Raw material availability is reflected in the preference of food industry location, with Shandong province having 15% of all food companies, leading the country. Henan, Hubei, Liaoning, Sichuan, Jiangsu and Guangdong provinces each have 6% of the industry located there. All other provinces and autonomous regions and cities have food industries present that use their local agricultural raw ingredients.

The size of the food industry is evenly distributed among large-, middle- and small-sized companies, with the large companies taking 31.3% of the total industry income, middle-sized companies 29.2% while small-sized company take 39.5% of the total industry income. The annual growth rates of the large-, middle- and small-sized companies are 11.89%, 9.35% and 14.8%, respectively, for the past decade.

4.3.2 Food Safety Concerns Damaged "Made in China" Products

Looking back, the Chinese food industry only started to wake up to renew itself after the terrible melamine incident in 2008. The damage was so huge that the whole food industry was faced with “made in China” products being considered unsafe in both domestic and international markets. Chinese people were buying infant formula from every possible foreign market and bringing it home to feed their babies. Chinese residing in foreign countries also avoided buying any Chinese food products, which led to great financial losses for the Chinese food industry.

Under such pressure, the Chinese central government started to change their strategy on food safety regulations and inspection technology. It started to adopt scientific principles and methods to perform inspections. They published the first Food Safety Law in 2009 [5], and revised it in 2015. However, inspection regulation still needs to move from the inspection of end products to the inspection of every step of the whole food chain from farm to table.

4.3.3 Moderate Speed Development of the Chinese Food Industry

Since 2011, the Chinese food industry has no longer been in the high-speed development and high-profit stage of the past. From Figure 4.3, one can see the gradual slowing in profit margin increases in comparison with previous years. For example, the increase was 8.6% for 2012, 7.4% for 2013 and 7.0% for 2014. This decreasing trend is expected to continue over the next few years.

4.4.4 Major Adjustment in Progress

In 2014, due to changes in consumer demands, the various food industries experienced changes. Purchases of natural products, meats and seafood increased, while demand for dairy products, frozen foods and beers declined. This reflected a consumer trend toward more safe, nutritious and healthy foods. It seems that the 2008 infant formula

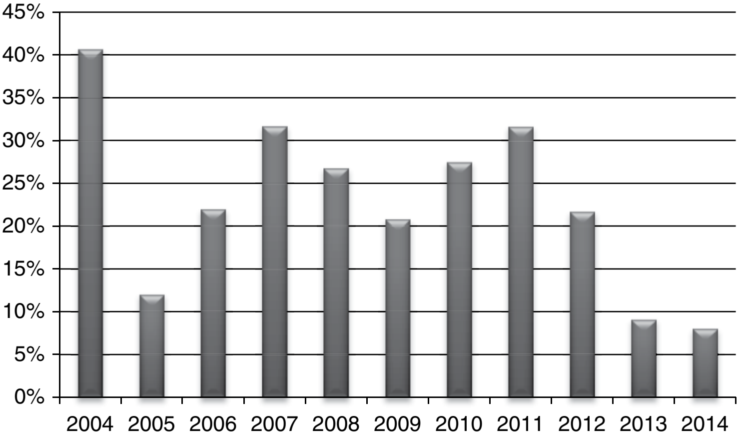


Figure 4.3 The percentage increases in total gross production value of Chinese food industry from 2004 to 2014.

incident [6] had lingered on and put a dampener on the whole dairy industry in China. It is not known when the dairy industry will regain consumer trust.

During the 1980s, the Chinese food industry was dominated by government-owned corporations, which produced 60% of the total output. Domestic private owners occupied 28% of the business, while foreign-invested companies (including those from Taiwan, Hong Kong and Macau) occupied only 12% of the food industry. By 2014, the domestic private corporations had gained control of 70.4% of the industry value. Many foreign-invested businesses were industry leaders in the past due to their management, personnel and investment advantages over domestic companies. The foreign companies played an important role in the upgrade of domestic food companies. However, the advantages of the foreign companies over domestic companies quickly disappeared as the domestic companies upgraded their management skills. The profit margins of the domestic private industry are now essentially the same as those of the leading foreign companies.

A major difference in the Chinese food industry in comparison with advanced nations is the size of the operation. Over 69% of the food companies in China are medium- and small-sized enterprises, which produce the bulk of the food products for the nation. It is on these enterprises that the government should place regulation control, inspection, and technology transfer and training courses to upgrade them to better food safety practices. By doing so, all Chinese citizens and consumers will benefit.

At the present time, the two major barriers facing the food industry in producing better food products are food safety practices and environmental contamination. For 2015 and the next few years, the upgrade of Chinese food industry and value-added food products are very important. The success or failure of the upgrades to medium- and small-sized food companies will likely decide the future of the Chinese food industry.

4.5 Challenges

The Chinese food industry is facing five major challenges at this time:

1) *Agriculture production*: With contamination from air, water and a polluted environment, safe raw materials have become a major problem for the food industry. The problem has no short-term solution. Since 2012, the food safety focus has moved from the end products to the ingredients and raw materials. In 2011, consumers were concerned about “convenience foods and food additives.” In 2012, it was “standards and inspection.” In 2013, it was “raw material contamination and intentional misleading.” In 2014, it was “microbial contamination, ingredient safety and food fraud.” [7] It clearly pointed to agriculture production as a major cause of unsafe food end products.
2) *Food fraud*: In 2014, inspection revealed the illegal addition of sugar substitute to wines and honey, and the substitution of industrial gum for food-grade gum in domestic markets. In Taiwan, low-quality oil added to high-priced oil was sold. All together, this was intentional cheating by businesses to make profit by fraud. In recent years, the use of illegal ingredients that cause serious food safety incidents has decreased in China. However, food fraud without food safety concerns, by using lower-quality products instead of expensive products to make profit, have increased

greatly in China. The media and consumers do not distinguish the two different kinds of food fraud and regard them both as food safety problems.

3) *Raw ingredients*: Since 2004, China has moved from a food ingredient exporting nation into an importing nation. The sources of raw materials have expanded into many countries and regions of the world. Many new ingredients are needed for new processed food products. Most of them have to be imported from foreign countries. AQSIQ used to concentrate on exported food products. Now, they are inspecting both imported and exported food products. Figure 4.4 shows the above changes [8].
4) *Consumer trust*: From 2011 to 2016, each January, the Chinese Institute of Food Science and Technology conducted face to face discussions between media and scientists of "food safety hot topics of the past year." From these meetings, it can be concluded that the accuracy of media reporting has been less than 25%. This media misinformation has led to consumers not trusting the government inspection system and the food industry. The food industry must understand that it has the primary responsibility for food safety. Safe foods are produced by the industry and they should not rely on the inspection system for food safety. The food industry must be responsible for producing safe and healthy food for consumers. Increase food safety knowledge within the food industry, the media and consumers is a major challenge.
5) *New food safety law*: The Chinese government used scientific information and spent seven years setting up the food safety standards. By 2015, the Ministry of Planned Parenthood and Health had established 492 standards covering over 11,000 items, which covered the whole food chain from production to consumption. More standards are in development. In many ways, 2015 was the year that the food safety standards were to be applied to the food processing industry. For example, the so-called "gold tinted wine" showed that the general consumer cares that products meet the national standards. In the past, random selected inspection of end products was the way to control food safety. It cost a lot, but it could not inspect the whole food chain.

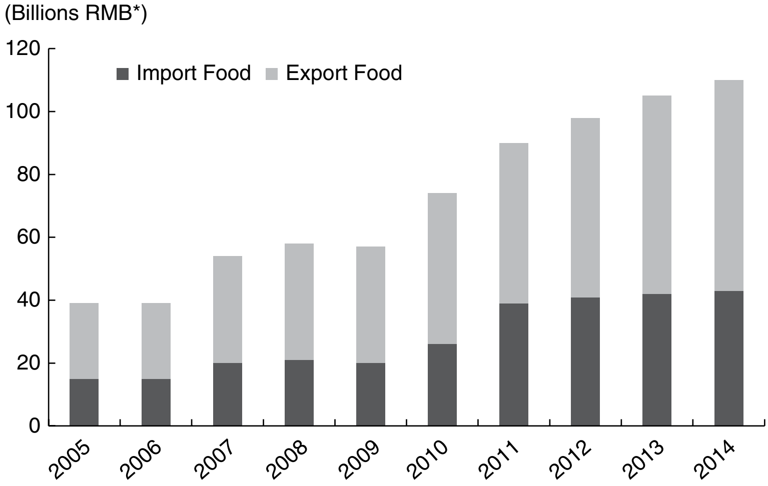


Figure 4.4 Food trade import and export from 2005 to 2014. RMB* = Chinese Yuan.

> It is time for a change in the process inspection system and a move to the inspection of critical points in the production end of the food chain. A new management style of inspection needs to be developed toward that end, much like the United States Food Safety Modernization Act, which places prevention over inspection [9].

From a marketing and management point of view, as expected, the cost of raw materials and labor are both increasing in China. Chinese foods produced with inexpensive labor and readily available raw materials are no longer the case and cannot compete with the international market. New safe, nutritious and healthy food products often need to have imported raw materials and additives. Clean-room processing must replace human labor to ensure food safety. Much like advanced countries, the end market businesses, like the huge supermarket chains, often have a strong influence on what food products are produced by the food processing industry. They also have top business negotiation staff that may put the food processing industry in a disadvantaged position. The end result is the lowering of the price to benefit the consumers, but also the lowering of the overall profits of the food processors. If this trend continues, the medium and small food industry will be slowly replaced by large processing companies and cooperatives. The other problem for the Chinese food processing industry is that media and consumer trust has not been recovered. It is probably unavoidable that larger investment, both domestic and foreign, is needed to upgrade the Chinese food processing industry and to further control the market in future years.

4.6 Future Development

1) *Marketing development trends*: Food safety has forced Chinese food processing to upgrade. To regain the trust of the general consumer, the food processing industry will need to work hard to establish brand names. Food markets will expand and medium and small companies are likely to merge into large corporations to be competitive to foreign-invested corporations. Consumer demands are likely to show two-polar movement, the high-priced, high-quality unique products at one end, the low-cost, but still safe food at the other. Business management practices and marketing will take more of a share of the total production costs. For example, it is likely that the purchasing of food products through the internet will become a normal habit for many consumers. To this end, processed foods are going to be one of the fastest new trends in consumer purchasing. More demand for traditional Chinese foods is likely to take place too. One example is that machines dispensed hot traditional lunches are already available in the office buildings of several big cities like Shanghai and Beijing. Nevertheless, how to solidify the place of traditional Chinese food in the overall food market development needs to be researched. There is no doubt that the food processing industry will still be one of the most active and potentially profitable manufacturing businesses in China.
2) *Industry development trends*: 2015 was the last year of the “twelfth national five-year plan.” It was also the year that saw the end of the high-speed transformation and upgrade of all industry in China. It was the year that we knew that China would be heading into a medium-speed development era. This is a historical time for all industries in China. From all the angles, we can predict that the food processing

industry will continue to be a major industry, with modest upgrade and transformation among all Chinese industries. If we analyze the situation in 2015, it is clear that central government places a high emphasis on food safety and the stabilization of food prices for consumers. It also realizes the need for the upgrade and survival of the food processing industry, whether large, medium or small enterprises. The stabilization of food prices depends greatly on the performance of the food processing industry. With the increased cost of input factors such as labor cost, resources, raw material cost and energy prices, the food industry in China is facing a great challenge for the future.

References

1 Wang, L.M. 2014. *Report of Food Industry Development for 2013.* Chinese Light Industry Publication Press. Beijing, China, p. 3.

2 *Food Products Operation Report for Jan. to Dec, 2014 in China.* http://www.miit.gov.cn/n1146312/n1146904/n1648366/n1648369/c3485306/content.html (accessed October 2016).

3 Chinese Light Industry Information Center. 2014. *Chinese Light Industry Competitiveness Report.* Chinese Light Industry Publication Press. Beijing, China.

4 Wang, L.M. 2015. *Report of Food Industry Development for 2014.* Chinese Light Industry Publication Press. Beijing, China, p. 4–7.

5 Chinese Food Safety Law, 2009, from Chinese national council. http://www.gov.cn/f1fg/2009-02/28/content.1246367 htm (accessed 2016).

6 Chen, J. 2009, What can we learn from the 2008 melamine crisis in China? *Biomedical and Environmental Sciences* 22: 109–111.

7 *Global Food Industry Food Safety and Nutrition.* Chinese Institute of Food Science and Technology. Beijing, China, p. 41.

8 AQSIQ Import and Export Division. 2014. *Food Safety Risk Analysis Report of Chinese Import and Export Food and Cosmetic Products for 2014.*

9 United States Food and Drug Administration. FDA Food Safety Modernization Act. https://www.gpo.gov/fdsys/pkg/PLAW-111publ353/pdf/PLAW-111publ353.pdf (accessed October 2016).

Part 2

Food Microbiology

5

Food-borne Diseases and Surveillance

Yunchang Guo[1]*, Shuyu Wu*[2] *and Jianghui Zhu*[1]

[1] *China National Center for Food Safety Risk Assessment, China*
[2] *US Centers for Disease Control and Prevention, China*

5.1 Introduction

Food-borne disease is defined as infectious or poisoning diseases arising from pathogenic factors in food entering into the human body [1]. The term food-borne diseases (or food-borne illness), officially first introduced in the Food Safety Law enacted in 2009, is a relatively new term for the public and for most public health professionals in China. Before 2009, food poisoning was a common term in China to describe any clustered illness related to food consumption. Infectious diarrhea was also used to indicate sporadic cases caused by enteric or food-borne pathogens.

In China, food safety has emerged as one of the most prominent concerns during the past decade, indeed the last 20 years. The government has made huge efforts on surveillance and control of food safety by focusing on inspection, primarily end-product testing. On the one hand, China has already established a rigorous system to inspect foods and markets, and this system has yet to detect substantial levels of microbial contamination [2]. On the other hand, the infrastructure and capacity of the food-borne disease surveillance system is still relatively limited in China. The gaps between China and industrialized countries with regard to food safety, including technical capacity, level of oversight and food hygiene supervision, remains significant. As economic development is unbalanced across different regions in China, many fragmented, small-scale, family workshop-style firms continue to dominate local food production. In addition, many communities have retained certain traditional cooking and eating habits, while they adapt to a new lifestyle observed in Western countries. All of these factors make the detection of food-borne diseases and food-associated outbreaks difficult. Due to the lack of systematically collected surveillance data, estimating the burden of food-borne illness on China's economy is likely to be unreliable [3].

The World Health Organization (WHO) has classified food-borne disease surveillance systems into four categories: (a) informal surveillance, (b) syndromic surveillance, (c) laboratory-based surveillance and (d) integrated food chain surveillance [4]. The four surveillance system categories require different resources and capacities, and have different effects for estimating the illness burden and detecting food-borne outbreaks.

Food Safety in China: Science, Technology, Management and Regulation, First Edition.
Edited by Joseph J. Jen and Junshi Chen.

This chapter will review and evaluate the past and current food-borne surveillance systems in China, and discuss the directions for future development. We use the year 2010 as a cut-off between the past and current period, when China started to establish a new national food-borne disease surveillance system.

5.2 The Past (–2010)

5.2.1 Reporting System of Food Poisoning and Infectious Diarrhea

In 1995, China issued *Food Hygiene Law* and a series of related guidelines, which required that food poisoning incidents involving more than 30 cases, or two or more deaths, or incidents occurring at school or during a regional or national critical activity period, should be reported to local or national government as emergency events [5]. For many years, China's surveillance of food-borne infections was limited to detection, response and reporting of point-source outbreaks (food poisoning) – those that occur at a restaurant or a large gathering, those that involve many ill persons who seek medical attention at a common facility and those that result from high-level contamination related to improper preparation, storage or provision of a food item [6].

An outbreak of severe acute respiratory syndrome (SARS) in 2003 served as the major transformative event in public health in China. Before SARS, the public health system was highly fragmented and poorly resourced, and overall disease surveillance was incomplete and slow. In response to SARS, China invested heavily in strengthening its tiered public health units (each known as a "Center for Disease Control and Prevention" (CDC)) around the country. China also established an Internet-based national notifiable disease reporting system to provide "real-time" statistics about various disease incidences, but its performance as a surveillance system for food-borne infections was inadequate [7]. This reporting system only defined cholera, dysentery and "other infectious diarrhea," and the data collected for each of these categories was limited. Patients infected with pathogens other than *Vibrio cholerae* and *Shigella*, such as *Salmonella*, *E. coli* O157, *Listeria* and *Campylobacter* should have be reported in the "other infectious diarrhea" category with the etiology added as a comment. However, among the large number of cases reported under this category, few included laboratory information. Overall, China lacked reliable data about the number of illnesses caused by many infections transmitted commonly by food and lacked a system to monitor trends of food-borne diseases.

In summary, before the *Food Safety Law* (revised from the former *Food Hygiene Law*) was formulated in 2009, the management of food-borne diseases in China focused on the control of mass food-poisoning incidents and food-borne communicable diseases transmitted human-to-human. Public health agencies only responded to food-borne emergencies in a passive way, "running around to put out a fire like a fireman". Due to the lack of an effective food-borne disease surveillance system, China was unable to estimate the food-borne illness burden, nor to detect widely dispersed outbreaks.

5.2.2 Analysis of the Previous Results of Food Poisoning Reports

After the issue of the new *Food Safety Law*, the MOH (Ministry of Health) started to establish a national food-borne disease surveillance system in 2010.

Here we summarize some findings from the previous food poisoning reports. During 1992–2010, a total of 8869 food poisoning incidents (554 incidents per year on average) were reported (data from 2002, 2007 and 2009 were unavailable), of which 84.3% had known causes. The top three causes were microorganisms (41.8%), chemicals (35.6%), and poisonous animals, plants and mushrooms (15.3%). During this period, a total of 231 514 individual food poisoning cases (14 469 cases per year on average) were reported. The majority of these cases were caused by microorganisms (119 023 patients, 51.4%), followed by chemicals (54 388 cases, 23.5%), and poisonous animals, plants and mushrooms (20 290 cases, 8.8%). A total of 1365 deaths (85 deaths per year on average) were reported during this period. The most frequent causes of death were chemicals (534 deaths, 39.1%), poisonous animals, plants and mushrooms (405 deaths, 29.7%) and microorganisms (157 deaths, 11.5%). The reported food poisoning incidents mainly occurred outside the home (e.g. hotels, restaurants and canteens), accounting for 58.1% of all cases. In addition, foods causing food poisoning were mainly fruits and vegetables, meat products and aquatic products [8–11].

During 1992–2010, the reported food poisoning incidents were mainly mass incidents involving more than 30 cases. Local officials frequently discouraged reporting food poisoning events involving less than 30 persons, as reporting the occurrence of food poisoning was regarded as poor governmental management. Therefore, food poisoning data collected by the reporting system were only the “tip of the iceberg” of food-borne outbreaks that actually occurred in China. Due to the lack of reliable data on the prevalence of food-borne diseases and temporal trends, it was impossible to estimate the overall illness burden accurately. This seriously hindered people’s full understanding of the significance of public health, and the implementation of evidence-based intervention to improve food safety. It was urgent for China to establish evidence-based risk assessment for food safety and laboratory-based sentinel surveillance for food-borne diseases.

5.3 Present (2010~)

5.3.1 Building a New Food-borne Disease Surveillance System

The year 2008, when the melamine in baby formula event occurred, was a significant “watershed” for food-borne disease surveillance in China. The MOH established new committees on food safety, stepped up inspections and published a list of banned food additives [12]. This incident also enabled the MOH to realize the importance of conducting food-borne disease surveillance, and establishing early warning and rapid response to food-borne diseases, in addition to monitoring food production and circulation. Identifying potential food safety hazards or unknown risks through testing a random sample of foods from a random sample of markets was determined to be insufficient. In fact, active surveillance of human illness should be the first step to determine what foods and what pathogens are making people ill. A public health system can detect food-borne clusters and outbreaks early through collecting data on human illness and laboratory diagnosis. By investigating these illnesses and determining their root causes, health officials can provide data to food producers and regulators to reduce hazards from the farm to the table.

The new *Food Safety Law* issued in 2009 specified that food-borne disease surveillance had officially become an important component of the national food safety risk monitoring system. The MOH was responsible for organization, implementation and launching of the food-borne disease management system as well as the development and coordination of the food-borne disease surveillance system [1,13]. In 2010, to facilitate the early detection of abnormal food-borne incidents, such as melamine-induced kidney stones in infants, a new reporting system was established to collect "abnormal" cases and "abnormal" health incidents associated with food, which could not be explained by existing clinical knowledge and experience. The limitation of this reporting system was discovered after a short period of implementation – that doctors could often not make explicit diagnosis and report such cases, due to the lack of specific case definition. Therefore, the number of reports to this system has been very limited and has included inaccurate reports.

In 2011, in order to enhance the attribution of food-borne outbreaks and determine the cause, process and nature of the outbreaks, the MOH modified the original food poisoning reporting system to a national food-borne disease reporting system. The new system required all-level CDCs to verify, investigate and report food-borne outbreaks involving two or more cases (no longer 30 cases). Until June 2015, this food-borne disease outbreak reporting system covered all provincial, municipal and county CDCs across China.

In 2011, the MOH launched a laboratory-based food-borne disease surveillance system. In this system, sentinel hospitals are required to identify food-borne pathogens including *Salmonella, Shigella, Vibrio parahemolyticus,* diarrheogenic *Escherichia coli*, Norovirus, *Listeria* and *Cronobacter* from stools of diarrheal patients. Bacterial isolates are required to be forwarded to public health laboratories in local CDCs for further subtyping and characterization. As of June 2015, a total of 3483 sentinel hospitals from 31 provinces are included, covering all county-level administrative regions. In 2013, in order to improve the capacity for early detection of dispersed food-borne outbreaks, a national food-borne disease molecular tracing network (TraNet) was launched, based on the existing laboratory-based food-borne disease surveillance system. In this network, 29 provincial CDCs conduct molecular typing using pulsed-field gel electrophoresis (PFGE) on food-borne bacterial strains submitted by sentinel hospitals within their jurisdiction, and submit PFGE results to a national database for further analysis.

Additionally, a pilot population survey about acute gastroenteritis was conducted in six provinces (Shanghai, Jiangsu, Zhejiang, Jiangxi, Guangxi and Sichuan) in 2010–2011, in an effort to better understand the prevalence of diarrhea, the frequency of seeking medical care and the financial burden of food-borne diseases.

In recent years, the Chinese government has been conducting a series of reorganizations to establish the best strategy for managing food-borne disease supervision. In 2011, a new public health agency called China National Center for Food Safety Risk Assessment (CFSA) was established. Managed by the MOH (http://www.chinafoodsafety.net/), CFSA is responsible for food safety risk assessment and food-borne disease surveillance in China.

In comparison with the past, China has made significant progress in the construction and management of the food-borne disease surveillance system. The system has expanded from outbreak reporting to more comprehensive surveillance. The mode of surveillance has changed from passive to active. However, China is still different from other industrialized countries in terms of social economy, population size, health care system and food safety situation. Given these differences, replicating systems used in Europe and elsewhere were unlikely to address the gaps and needs for a food-borne disease surveillance system in China. China is currently developing and implementing a food-borne disease surveillance system using a step-by-step approach that addresses existing regional, economic and traditional differences across the country.

5.3.2 Outcomes of Current Food-borne Disease Surveillance

Since 2011, food-borne disease surveillance in China has been officially incorporated into the national Food Safety Action Plan. The MOH and other relevant departments of the State Council have organized the implementation of the action plan, and have attempted to establish an active food-borne disease surveillance, to estimate food-borne illness and attribute to risky foods [14].

During 2011–2014, the timeliness of outbreak investigation and reporting has been greatly improved, and the rate of misreporting has decreased. The number of reported food-borne outbreaks increased from 554 per year during 1992–2010 to 1046 per year during 2011–2014. Data from the system have identified the role of high-risk foods and risk factors in outbreaks caused by pathogens, chemical factors and poisonous animals and plants. During 2011–2014, 4184 outbreaks (1046 per year), 59 356 cases (14 839 per year) and 411 deaths (103 per year) were reported. The cause that resulted in the most cases was microorganisms (27 479 cases, accounting for 46.3%), followed by poisonous animals and plants (8838 cases, 14.9%), poisonous mushroom (4406 cases, 7.4%) and chemicals (4283 cases, 7.2%). At the same time, the major causes of deaths were consumption of poisonous mushrooms (215 deaths, 47.9%), followed by chemical exposures (103, 22.9%), poisonous animals and plants (52, 11.6%) and microorganisms (36, 8.0%). Comparison of the data from 2011–2014 with that of 1992–2010 supports the relatively high burden of food-borne diseases caused by microorganisms and highlights the importance of food safety in China. The top five bacterial pathogens responsible for food-borne outbreaks in China are *Vibrio parahaemolyticus, Salmonella, Staphylococcus aureus* (enterotoxin), *Bacillus cereus* and diarrheagenic *Escherichia coli*. Eating out (including hotels, restaurants, fast food restaurants and enterprise canteens) is the most common location for food-borne outbreaks, accounting for 55.4% of reported outbreaks. Ready-to-eat food such as fruits and vegetables, meat and aquatic products are also associated with a high outbreak risk. Such risks mainly result from cross-contamination of microorganisms during food handling, indicating poor compliance with hand and food hygiene practices.

A substantial increase in the percentage of reported food poisoning events occurring at home was also noted from 32% (2004) to 40% (2014). In addition, most deaths during outbreaks occurred at home, often caused by *Pseudomonas cocovenenans* subsp. *farinofermentans*, botulinum toxin, tetrodotoxin and poisonous mushroom, suggesting lack of food safety knowledge among the public. Therefore, increasing public awareness about food safety and hand hygiene is an important element of preventing and controlling future infections and food-borne disease outbreaks. At the same time, food-borne disease outbreaks caused by chemicals decreased from 35.6% in 2004 to 12.9% in 2014. This decrease was probably associated with the progress in controlling illegal use and misuse of food additives, pesticides and veterinary drugs.

In addition to enhancing outbreak reporting, active sentinel surveillance and population surveys on food-borne infections were carried out to estimate a baseline prevalence and burden of food-borne diseases. The positive rates of food-borne pathogens from diarrheal patients are: *Salmonella* (2.6%), *Vibrio parahemolyticus* (1.9%), diarrheagenic *Escherichia coli* (1.5%), *Shigella* (0.5%) and Norovirus (10.1%). In the pilot population survey, 39 686 people across six provinces were investigated. The overall incidence of acute diarrhea was 0.56 episodes per person-year with over 2.16 million episodes caused by food (incidence 0.16 episodes per person-year), namely, about 1 in 6.4 people suffers from food-borne diseases each year [15,16]. Currently, the burden of food-borne diseases caused by individual pathogens is being analyzed, using data from sentinel food-borne disease surveillance.

The food-borne disease surveillance has recently generated data to support that *Listeria monocytogenes* contamination in food is a risk factor for listeriosis infection among pregnant women. In 2014, 14 listeriosis cases were reported in sentinel hospitals from six provinces, including nine perinatal patients (three abortions, one stillbirth, one newborn death and four infant survivals) and five non-perinatal patients (three cures and two deaths). Investigation of four patients indicated that the infection was possibly associated with eating contaminated ready-to-eat meat products. In the United States, public health officials estimate the incidence of listeriosis infection at 2.6 cases per 100 000 population, with 1600 new infections reported each year [17]. In the EU, the estimated incidence is 0.3 cases per 100 000 populations with 1500 new cases each year [18]. Considering population size and food contamination level in China, the incidence of listeriosis is probably much higher than that in developed countries. There is a need for China to improve the surveillance of *Listeria* infection in order to obtain the real burden of listeriosis in China and to develop intervention strategies to minimize the risk of future infections.

TraNet has played a significant role in identifying the etiologic causes and in tracking contaminated food in several food-borne outbreaks. During September 26–29, 2013, seven hospitals in Beijing discovered *Salmonella* enteritis infection among students who came from three middle schools located in two separate districts in Beijing. A total of 89 students were infected without deaths. An analysis of isolated *Salmonella* strains by CFSA in collaboration with Beijing CDC demonstrated that the 28 strains isolated from patients' stools shared the same PFGE pattern. Epidemiological investigation showed that all of the infected students had eaten the same brand of spicy chicken filet hamburger produced by one food company. In addition, three *Salmonella* enteritis strains were isolated from the suspected chicken hamburger and residual chicken for production, and their PFGE patterns were identical with the strains from the patients. TraNet has provided important evidence to identify the cause of this outbreak. However, TraNet is being further developed in order to efficiently detect outbreaks dispersed over a wider geographic area.

5.4 The Future

The food-borne disease surveillance system in China is still in the early stage of development in a step-wise fashion. In comparison with some industrialized countries, food-borne disease surveillance and control are relatively new for public health officials in

China. The United States is one of the few countries in the world that has generated good estimates of disease burden caused by food-borne infections. In 2011, the USCDC estimated that 48 million cases of food-borne diseases occur each year, resulting in 128 000 hospitalizations and 3000 deaths. Approximately 90% of these food-borne infections are caused by seven pathogens: *Salmonella*, Norovirus, *Campylobacter, Toxoplasma gondii, Escherichia coli* O157, *Listeria* and *Clostridium perfringens* [17]. These data reflect many years of work by experts in surveillance, laboratory detection, epidemiological investigation and statistical analysis. The EU has also established an excellent food safety system, which allows tracking of food items from production to consumers and tracing from consumers back to food production. This system has played a significant role in identifying the sources of food-borne infections [18]. Experiences and lessons learned from other industrialized countries can be adapted to China's social economy, medical system, and food production and safety frameworks, as well as to the country's regional differences. There is a great need in China to improve the capacity for rapid and accurate laboratory detection, as well as for epidemiological outbreak investigations. Establishing a functional and responsive population-based food-borne disease surveillance system will rely on strong capacity in these areas.

Within this context, the two major goals for China's food-borne disease surveillance are: (a) to generate accurate estimates of the food-borne illness burden in the country, and (b) to identify the etiologic cause and source of food-borne infection. The following enhancements should be considered to strengthen food-borne infection detection and control in China [6]:

1) Strengthen cooperation and information sharing between public health agencies, clinical hospitals, food and drug supervision agencies and agricultural agencies, to facilitate the development of a comprehensive food-borne disease surveillance system.
2) Provide training to physicians, epidemiologists and microbiologists to improve the capacity of outbreak investigation and laboratory diagnosis.
3) Require public health laboratories to provide services to clinical laboratories, including assistance with testing specimens from complex cases or performing additional microbiologic tests on negative specimens.
4) Reduce the turnaround time of case reporting, laboratory testing, molecular typing and data analysis, and increase the efficiency of outbreak detection and response.
5) Increase the percentage of the population included in the food-borne surveillance system, and similarly, improve the geographic representativeness of surveillance data.
6) Compile, analyze and publish summaries of surveillance data and outbreak investigations each year; and increase the use of surveillance data to guide evidence-based policy changes.

5.5 Brief Summary

For the past few years, China has been striving to enhance their food-borne disease surveillance approach and methodology so that it will be more suitable for the country, and has been striving to improve the collection and use of surveillance data for policy decisions. However, a comprehensive system of food-borne disease surveillance will require many more years and strong collaboration between agencies in China. It is anticipated that China will continue to strive for and build a well-functioning integrated food-borne surveillance system, where clinicians, microbiologists and epidemiologists work together to generate and share data, and public health officials always use scientific evidence to guide policies. Such a system will more accurately describe the human health burden of food-borne illness in China and help to improve food safety in China.

Disclaimer

The findings and conclusions in this report are those of the authors and do not necessarily represent the official position of the US Centers for Disease Control and Prevention.

References

1 Food Safety Law of the People's Republic of China. English language translation available at http://apps.fas.usda.gov/gainfiles/200903/146327461.pdf (Accessed on 21 June 2016).

2 Pei X, Li N, Guo Y, Liu X, Yan L, Li Y, Yang S, Hu J, Zhu J, Yang D. Microbiological Food Safety Surveillance in China. *International Journal of Environmental Research Public Health*. 2015 Aug 28;12(9):10662–70.

3 Food safety in China: A mapping of problems, governance and research. Forum on Health, Environment and Development (FORHEAD), Working Group on Food Safety. February 2014. http://webarchive.ssrc.org/cehi/PDFs/Food-Safety-in-China-Web.pdf (Accessed on 21 June 2016).

4 Second FAO/WHO Global Forum of Food Safety Regulations. Monitoring and Food Safety Quick Alarm System for Food-borne Diseases. 12–14 October 2004, Bangkok, Thailand.

5 National Health and Family Planning Commission of the People's Republic of China. *Food Poisoning Accident Processing Guideline*. Available at: http://www.nhfpc.gov.cn/zhuzhan/wsbmgzl/200804/5a84c866a32c444a9c498f66e2c5496d.shtml. (Accessed on 20 June 2016, in Chinese).

6 Varma JK, Wu S, Feng Z. Detecting and controlling foodborne infections in humans: lessons for China from the United States experience. *Global Public Health*. 2012;7(7):766–78.

7 Ma JQ, Yang GH, Shi XM. Information technology platform in China's disease surveillance system. *Disease Surveillance* 2006;21:1–3.

8 Liu X, Chen Y, Wang X, Ji R. Foodborne disease outbreaks in China from 1992 to 2001 national foodborne disease surveillance system. *Journal of Hygiene Research*. 2004;33(6):725–7. [Article in Chinese]

9 Liu X, Chen Y, Fan Y, Wang M. Foodborne disease outbreaks in China in 2003 national foodborne disease surveillance system. *Journal of Hygiene Research*. 2006, 35(2):201–4. [Article in Chinese]

10 Wang J, Liu X. Analysis on Current Situation of Food Poisoning in China. *Chinese Journal of Health Inspection*. 14(6):426–8. [Article in Chinese]

11 Chen Y, Guo Y, Wang Z, Liu X, Liu H, Dai Y, Tang Z, Wen J. Foodborne disease outbreaks in 2006 report of the National Foodborne Disease Surveillance Network, China. *Journal of Hygiene Research*. 2010;39 (3):331–4. [Article in Chinese]

12 Melamine and food safety in China (editorial). *Lancet*. 2009;373:353.

13 Implementation Rules of Food Safety Law of the People's Republic of China, Order of the State Council of the People's Republic of China No. 557. English language translation available at http://gain.fas.usda.gov/Recent%20GAIN%20Publications/Final%20Food%20Safety%20Law%20Implementation%20Measures_Beijing_China%20-%20Peoples%20Republic%20of_8-14-2009.pdf (Accessed on 20 June 2016).

14 Notification of issuing the "Food Safety Action Plan" by the Ministry of Health. Available at: http://www.gov.cn/gongbao/content/2004/content_62680.htm (accessed on 20 June 2016, in Chinese).

15 Chen Y, Yan WX, Zhou YJ, Zhen SQ, Zhang RH, Chen J, Liu ZH, Cheng HY, Liu H, Duan SG, Lan Z, Sun JC, You XY, Li JG, Wu YN. Burden of self-reported acute gastrointestinal illness in China: a population-based survey. *BMC Public Health*. 2013; 8(13):456.

16 Li B, Luo J, Tan H, Ke B, He D, Ke C, Klena JD, Zhang Y. Phenotypic and phylogenetic analysis of *Vibrio parahaemolyticus* isolates recovered from diarrhea cases in Guangdong Province. *International Journal of Food Microbiology*. 2015; 4(200):13–17.

17 Scallan E1, Hoekstra RM, Angulo FJ, Tauxe RV, Widdowson MA, Roy SL, Jones JL, Griffin PM. Foodborne illness acquired in the United States: Major pathogens. *Emerging Infectious Diseases*, 2011;17(1):7–15.

18 Denny J, McLauchlin J. Human *Listeria monocytogenes* infections in Europe: An opportunity for improved European surveillance. *Eurosurveillance*. 2008;13(13). pii: 8082.

6

Food-borne Pathogenic Bacteria

Xianming Shi[1]*, Yanping Xie*[2] *and Xiujuan Zhou*[1]

[1] *School of Agriculture and biology, Shanghai Jiao Tong University, China*
[2] *Eastern Regional Research Center, US Department of Agriculture, USA*

6.1 Introduction to Bacterial Food Poisoning

Food-borne illness is defined by the World Health Organization (WHO) as "diseases, usually either infectious or toxic in nature, caused by agents that enter the body through the ingestion of food." Food poisoning remains a global public health challenge. More than 200 diseases are caused by unsafe food contaminated by harmful bacteria, parasites, viruses, toxins and chemical substances, according to the WHO. The WHO estimates that worldwide food-borne and water-borne diarrheal diseases taken together kill about 2.2 million people annually. It is one of the leading causes of illness and death worldwide. Bacteria, however, are the most common cause of food poisoning, a distressing and sometimes life-threatening problem for millions of people throughout the world. Official data showed that an annual average of 300 million people in China contract food-borne diseases. It is estimated that 56.1% of food poisoning outbreaks were caused by microorganisms in China in 2012 [1].

Bacterial food poisoning is often caused by the consumption of foods contaminated with bacteria or their toxins, resulting in typical symptoms of gastroenteritis [2]. The most common food-borne infections in China, based on recent reports, are those caused by the bacteria, *Salmonella*, *Vibrio parahaemolyticus, Staphylococcus aureus*, *Listeria monocytogenes*, *Escherichia coli* O157:H7 and *Clostridium botulinum* [3], which are commonly found in many raw foods. Normally the presence of a large number of food poisoning bacteria are essential to cause illness. Therefore, illness can be prevented by controlling the initial number of bacteria present, preventing the small number from growing, destroying the bacteria by proper cooking processes and avoiding recontamination.

Salmonella, which tops the list of bacterial food poisoning organisms in mainland China, causes 40% of the food-borne infections [4]. On the eastern coastline of China, however, *Vibrio parahaemolyticus* becomes the primary pathogen causing food poisoning [5]. *Staphylococcus aureus* is considered to be the third most common pathogen, causing 20–25% of outbreaks of food poisoning [6]. In addition, present rates of *Listeria monocytogenes* are around 2.7–7.1%, and 24.4–60% in some areas of China [7]. It is

Food Safety in China: Science, Technology, Management and Regulation, First Edition.
Edited by Joseph J. Jen and Junshi Chen.

reported that *Esherichia coli* O157:H7 has been found frequently in meat products in recent years, which is also one of the major pathogens highlighted by the public health agency. *Clostridium botulinum* is another important pathogen widely distributed in nature, which produces dangerous botulinum toxins.

The China CDC reported that most bacterial food poisoning resulting in deaths in China occur from May to September [8]. The main reasons are high temperatures and high humidity causing food spoilage and bacterial growth. The temperature range in which most bacteria can grow is between 40 °F (5 °C) and 140 °F (60 °C). The age distributions of patients with food-borne illness in China are 1.9% 0–5 years old, 28.4% 6–15, 67.1% 16–60 and 2.6% >60. Many more cases of 6–15-year-olds with food-borne disease cause hospitalization and death than other ages [9], and more attention should be paid to this age group.

Outbreaks and sporadic cases of food-borne disease are regular occurrences in all countries of the world. Foods that are most frequently associated with food-borne illness include vegetables, eggs, meat and ready-to-eat food. Illnesses can arise from these foods whether they are produced on large or small scales, purchased from major retailers or local markets, or whether home-cooked or prepared and eaten outside the home. In response to food-borne diseases, all that can be done is to improve food safety incrementally by systematically concentrating on reducing the risks of contamination at every point in the food supply chain, from production and processing to distribution, storage, preparation and consumption, at home and in retail food service establishments.

6.2 Important Food-borne Pathogenic Bacteria

6.2.1 *Salmonella*

Salmonella is a genus of Gram-negative bacteria with similar antigenic structures and biological characteristics. These bacteria are typically motile, non-spore-forming and facultative aerobes, with an optimum temperature of 35–37 °C for growth. All the serotypes except of *S. pullorum* and *S. gallinarum* show flagella. According to WHO reports, consumption of food contaminated with *Salmonella* is a major cause of food-borne illness throughout the world. Food (especially meat) is one of the most important sources of human salmonellosis. In China, more than 90% of *Salmonella* outbreaks are commonly associated with food products that come from animals.

Salmonella has various serotypes, some of which can cause cross infection between humans and animals. Over 2600 different serovars have been differentiated by their antigenic presentation [10] and about 300 serovars have been reported in China [11]. The common serotypes causing food poisoning include *S. typhimurium*, *S. enteritidis*, *S. choleraesuis* and *S. infantis*.

So far, *Salmonella* infection treatment mainly depends on the antibiotic. For example, ceftriaxone and ciprofloxacin are two major kinds of antibiotic being used in the treatment of *Salmonella* infection. However, with the use and abuse of antibiotics, there have been significant increases in the occurrence of resistance in *Salmonella*, which also results in multidrug-resistant *Salmonella*. Relevant monitoring data showed that multidrug resistance of *Salmonella* species has increased from 20–30% in the 1990s to 70% in the early 2000s [12]. During 2010 to 2012, the proportion of resistant food-borne *Salmonella* steadily increased. In addition, the proportion of multidrug-resistant *Salmonella* strains increased from 23.1% in 2010 to 81.8% in 2012 [13]. It is predicted that the resistance rates will increase substantially and the antibiogram will broaden.

6.2.2 *Vibrio parahaemolyticus*

Vibrio parahaemolyticus is a Gram-negative bacterium found in brackish saltwater, commonly known as a halophile, which is mainly distributed in coastal regions. Ingestion of bacteria in raw or undercooked seafood, usually oysters, is the predominant cause of the acute gastroenteritis caused by *V. parahaemolyticus*. In recent years, multiple outbreaks of *V. parahaemolyticus* infection have been reported in Asia (especially Southeast Asia), Europe and North America. According to the Chinese food-borne disease monitoring network data [14], the scale and population exposure range of food poisoning caused by *V. parahaemolyticus* has significantly increased in coastal areas in recent years.

However, only some of the *V. parahaemolyticus* strains are pathogenic, which usually produces various virulence factors, including hemolysin, urease and adhesion molecules. Hemolysin has been demonstrated to be the main reason *V. parahaemolyticus* causes illness, including thermostable direct hemolysin (TDH), TDH-related hemolysin (TRH) and thermolabile hemolysin (TLH) [15]. *V. parahaemolyticus* usually shows a strong ability to survive, especially because of the heavy use of antibiotics in aquaculture, which strengthens strain competition and leads to drug-resistant strains. Even *V. parahaemolyticus* strains without TDH toxin factors spread and are transferred from seafood to other kinds of food. In recent years, food poisoning cases caused by *V. parahaemolyticus* have been determined by the source of the pathogen; however, in most of the cases the source of the pathogens was not found due to incomplete sample collection records and other reasons. At present there are many reports on how to control *V. parahaemolyticus* from food sources [16], but only a few studies focus on tracking the source of *V. parahaemolyticus* during food processing, marketing and consumption.

6.2.3 *Staphylococcus aureus*

Staphylococcus aureus is a Gram-positive, non-motile coccal bacterium. It is found in grape-like (staphylo-) clusters. *S. aureus* is widely distributed in nature and carried by 30–50% of normal individuals, and shows strong resistance to various physical and chemical factors. Foods that have been frequently implicated in *S. aureus* food poisoning are meat and meat products, poultry and egg products. Raw milk and unpasteurized dairy products may contain large numbers of *S. aureus*, usually as a result of staphylococcal mastitis.

The pathogenicity of *S. aureus* is a complex process involving the coordinated expression of around 40 kinds of diverse virulence factors. These virulence factors mainly belong to cell surface binding proteins and secreted proteins [17], such as hemolysin, enterotoxin, lipases, proteases and thermonucleases, among which enterotoxins are a major cause of food poisoning. Staphylococcal enterotoxins (SEs) are low-molecular weight proteins (26.9–29.6 kDa) that are heat resistant and are able to withstand a temperature of 100 °C for 30 minutes. To date, there are 21 identified SEs and staphylococcal-like enterotoxin (SEl) genes, including *sea* to *see*, *seg* to *sev*. It is suggested that more types of SEs exist in nature.

In recent years, infections by multidrug-resistant *S. aureus* not only occur in hospitals, but are also involved in community-associated transfer, which then becomes an unusual public health threat. In 1961, British scientists identified the first strain of *S. aureus* that had resistance to methicillin. In 1968, the first hospital outbreak of methicillin-resistant *S. aureus* (MRSA) in the United States was reported in Boston, MA. The increased spread of MRSA infections occurred in the following several decades due to the use of beta-lactam antibiotics. Moreover, the rate of infection and mortality caused by MRSA infections is increasing year on year. In China, there were over 60% MRSA strains isolated from patients infected by *S. aureus* in 2009 [18], and the proportion of MRSA isolates is getting higher each year. However, the current higher levels of antibiotic-resistant bacteria are attributed to the overuse and abuse of antibiotics, which has attracted widespread attention from the international community.

6.2.4 *Listeria monocytogenes*

Listeria monocytogenes is a gram-positive, non-spore-forming, motile, facultatively anaerobic, rod-shaped bacterium. It has a wide temperature range (–0.4-50 °C) for growth, while its optimum is between 30 and 37 °C. *L. monocytogenes* consists of 16 serovars: 1/2a, 1/2b, 1/2c, 3a, 3b, 3c, 4a, 4ab, 4b, 4c, 4d, 4e, 5, 6a, 6b and 7. Despite the widespread occurrence of *L. monocytogenes* in nature, only three serotypes (4b, l/2a, and l/2b) account for 98% of human infections. Moreover, serotype 4b causes the largest number of outbreaks and outbreak-associated cases. Serotypes 1/2a and 1/2b are usually found in sporadic outbreaks.

L. monocytogenes is an important food-borne pathogen, causing the disease listeriosis, with a high mortality rate of about 20–40% [19], including abortion, sepsis and meningoencephalitis. In recent years, there have been many outbreaks of listeriosis reported in the United States and Europe. Many sporadic outbreaks have also been reported in China and show a rising trend. In certain provinces of China, the occurrence rate of *L. monocytogenes* from food samples is 20% or more.

The United States, Europe and other countries have started to control contamination of *L. monocytogenes* in food. *L. monocytogenes* has also been determined as a monitoring target for the safety of food in China. Generally speaking, when *L. monocytogenes* is lower than 100 colony-forming units (CFUs) per gram in food, the risk of infection is low. Therefore, the EU used to allow the appearance of *L. monocytogenes* in food. In the United Stated, a "zero tolerance" approach was taken for *L. monocytogenes* in ready-to-eat food in the 1980s. In 2007 the United States established a regulatory limit of 100 CFU/g for *L. monocytogenes* in foods that do not support growth of the microorganism. Ready-to-eat food in which the growth of *L. monocytogenes* can occur requires its absence in 25 g of food (zero tolerance). In Hong Kong, China, the detection limit in ready-to-eat foods for *L. monocytogenes* has also been revised to be in line with the United States [20]. In mainland China, the food safety national standard limit of pathogens in food products (GB 29921-2013) was published in 2013 [21], which showed that *L. monocytogenes* should be absent in ready-to-eat food.

6.2.5 *Escherichia coli O157:H7*

Escherichia coli O157:H7 is an enterohemorrhagic serotype of the bacterium *E. coli*, which causes food-borne illness, typically through consumption of contaminated food.

Infection may lead to diarrhea, hemorrhagic colitis and serious complications like hemolytic uremic, thrombotic thrombocytopenic purpura. In the 1990s, *E. coli* O157 outbreaks were reported in some areas of China. In recent years, *E. coli* O157 has had a high detection rate in food samples in China, especially from meat products. It has been reported that several kinds of food have been found to contain *E. coli* O157 in Fujian, Beijing and Shanghai [22,23].

E. coli O157:H7 can be spread through a variety of ways. For example, contaminated meat and meat products, unpasteurized (raw) milk, contaminated raw fruits and uncooked vegetables during the picking process, untreated drinking water, and irrigation water [24] may be carriers of *E. coli* O157. Infection with *E. coli* O157:H7 follows ingestion of contaminated food or water, or oral contact with contaminated surfaces. It is highly virulent, with a low infectious dose: an inoculation of fewer than 10 CFU of *E. coli* O157:H7 is sufficient to cause infection.

The pathogenic mechanism of *E. coli* O157:H7 infection has still not yet been satisfactorily explained. Its virulence factors mainly include adhesion and shiga toxins. It is generally accepted that the *E. coli* O157:H7 bacterium latches onto the surface of an intestinal epithelial cell using long rope- or chain-like pili, which reduces the chance of being removed through bowel movements and reduces or delays the host's cellular immune response. Then the infection begins with rapid proliferation and toxin production, which damages host cells and leads to illness. Generally speaking, shiga toxins are the main virulence factors and the ability to produce shiga toxins is a primary feature of *E. coli* O 157:H7 [25]. Hemoclastic factors and adhesin are also virulence factors in *E. coli* O157:H7.

6.2.6 *Clostridium botulinum*

Clostridium botulinum is a Gram-positive, rod-shaped, anaerobic, spore-forming, motile bacterium with the ability to produce the neurotoxin botulinum. It is widely distributed in nature: in soil and water, on plants and in the intestinal tracts of animals and fish. *C. botulinum* usually has a strong ability to survive in canned food and sealed, pickled foods. The bacterium itself is not harmful and easily killed by heat. However, the spores of *C. botulinum* have high heat resistance and are able to survive for long periods in air. *C. botulinum* produces botulinum toxin under suitable environmental conditions. Botulinum toxin is a neurotoxin that causes descending, flaccid paralysis of the muscles, including those of the respiratory system, and is one of the most poisonous known natural toxins. Food-borne botulism is a severe type of food poisoning caused by the ingestion of foods containing the potent neurotoxin formed during growth of the organism. The incubation period is usually 1–7 days; mortality is 2.5–44%.

Usually, the majority of strains produce toxin of a single antigenic type. Different isolates of *C. botulinum* produce toxins that differ in antigens, and eight toxin types (A, B, Cα, C β, D–G) have been identified. Botulism in humans is almost always caused by strains producing toxin types A, B or E, and occasionally toxin type F [26].Toxin types A and B are the most common, toxin type E occurs in fish products. Most botulinum toxin reported in China is type A. Botulism in most other countries or areas is usually due to the ingestion of spore-contaminated canned food, ham, salami, cheese, salad, raw vegetables (such as peas), and so on. Infant botulism was first described in 1976. The most common cause of infant botulism is the consumption of contaminated honey or the use of honey pacifiers. In China, most botulism is caused by fermented soy products and flour products. According to data from Xinjiang, the most common area for botulism outbreaks, fermented soy products (tofu, bean paste, etc.) accounted for more than 80%, fermented flour products (sweet bean paste) and other causes accounted for about 10% [27]. In recent years, with the improvement of the economic situation in China, the proportion of both meat products and frozen food has increased, and the authorities should be vigilant for botulinum toxin poisoning caused by meat and improperly refrigerated food.

6.3 Frequent Vehicles of Food-borne Pathogens

Safe food supplies support national economies, trade and tourism, and contribute to food and nutrition security. Food-borne diseases usually originate from a wide variety of different foods contaminated by many different pathogenic bacteria during the food chain, from farm to table. Triggers are material contamination, food deterioration, improper storage and incorrect processing. Normally a certain number of food-poisoning bacteria must be present to cause illness. Therefore, illness can be prevented by controlling the initial number of bacteria present, preventing the small number from growing and destroying the bacteria by proper cooking or other methods, as well as avoiding recontamination.

6.3.1 Food Category

Foods that are most frequently associated with food-borne illness include vegetables, meat and ready-to-eat food. Illnesses arises from these foods whether they are produced on large or small scales, purchased from major retailers or local markets or whether home-cooked or prepared and eaten outside the home.

6.3.1.1 Vegetables and Fruits

The vegetables and fruits markets together are the largest sector of the retail food market in China, which is the largest world producer of fruit and vegetables (www.industrialnewsupdate.com). Many products are certified as organic and chemical free, but there are no control measures regarding the presence of manure or cattle feces. Fresh produce, therefore, is increasingly becoming a vehicle for transmitting enteric diseases of many different types. Leafy greens are contaminated most commonly with *E. coli* O157:H7 and *Salmonella,* which come from human or animal excrement; for example, from run-off from nearby farms or communities, or from contaminated irrigation water. Fresh tomatoes and cucumbers are a popular commodity in homes and food service around the world. The inherent risks of contamination by food-borne pathogens present a challenge to the produce industry and regulators. Since these tomatoes and cucumbers are intended to be consumed fresh, there is no “kill-step” in the processing that would eliminate pathogens if they were to become contaminated. The consumption of raw tomatoes and cucumbers has been linked to a number of *Salmonella* outbreaks. The bacteria are able to enter plants through roots or flowers and enter the tomato fruit through small cracks in the skin, the stem scar or the plant itself. Fruit products are also being increasingly implicated in outbreaks resulting from pathogenic bacteria.

6.3.1.2 Egg products

In recent years, *Salmonella* in eggs has been a major problem for public health agencies. Most illnesses caused by contaminated eggs are linked to *Salmonella*. *S. enteritidis* (SE) infects egg-laying poultry flocks, which results in some of the eggs containing the organism. The bacteria can be introduced to eggs via external fecal contamination of the shells, or from infected reproductive tissues of poultry prior to shell formation. The tricky thing is that contaminated eggs usually look normal, but still cause many outbreaks around the world, associated with omelets, quiche, meringues, desserts and cakes containing egg ingredients, eggnog and ice cream. For example, one of the largest SE outbreaks occurred in 1994, in which there were an estimated 224 000 cases in several US states, resulted from consumption of ice cream. Proper egg handling and cooking are able to destroy most of the bacteria. However, they have the ability to multiply in raw or “runny” eggs, food items that contain raw eggs (such as mango pudding and mayonnaise), or egg dishes held at improper temperatures (such as scrambled eggs at a buffet).

6.3.1.3 Meat and Poultry

It has been recognized that *Salmonella* has been transmitted by meat and poultry for many decades. Typically, undercooking, improper cooling or cross-contamination are the main causes of food-borne pathogenic bacteria transmission, due to limited food safety knowledge. In particular multidrug-resistant *S. typhimurium* definitive phage type 104 (DT 104) has emerged during the last decade as a global health problem because of its association with animal and human disease. *E. coli* O157:H7 was first identified as a food-borne pathogen in 1982 from two outbreaks resulting from hamburgers served in fast food restaurants of the same chain in the United States. *Campylobacter* has been involved in outbreaks and epidemiological studies with undercooked chicken and meat.

In recent years, ready-to-eat meat products have exhibited consistently increasing market share in China. From the farm to the consumer, growth conditions and nutrient content are potentially provided to support unwanted microbial growth during the processing, transportation and storage of meat products. Before consumption, these products do not require additional bactericidal treatment, so the contamination of ready-to-eat meat products by food-borne pathogens continues to draw attention. It is reported that commercial ready-to-eat foods in China have prevalence levels of food-borne pathogens that are comparable to those observed in other countries. From the perspective of food safety, heating food before eating is a good way to prevent unsafe exposure to food-borne pathogens.

As a special Chinese food, preserved meats, known locally as Lap-mei, are a kind of favorite food to many people, distinctive for their color, aroma and taste. These meats come in three types available on the local market: preserved Chinese sausages, preserved pork and preserved duck. Recently, the media reported that some people tried to prepare their own home-made Lap-mei, which raised food safety concerns. Some of the curing ingredients used to prepare Lap-mei (e.g. salt) have antimicrobial functions while sodium nitrate/nitrite has ability to inhibit the growth of *Clostridium botulinum* and its toxin production. Improper conditions in the processing of Lap-mei may lead to food deterioration due to bacterial growth, and may damage health after consumption. However, it is worth noting that *Clostridium botulinum* may grow in oxygen-free and low-acid food (such as home-made Chinese sausages) and produce the lethal toxin without causing noticeable deterioration in the food.

6.3.1.4 Fish and Shellfish

Vibrio parahaemolyticus is a pathogen that occurs naturally in warm waters. *V. parahaemolyticus* outbreaks associated with consumption of raw or improperly cooked seafood or salted food commonly occur in summer. *V. parahaemolyticus* generally appears in freshly harvested seafood at a level below the predicted dose to cause infection, and is extremely sensitive to heat. However, at ambient temperature, the organism multiplies rapidly to a sufficient infectious dose. *Listeria monocytogenes* is present in marine waters, especially if there is agricultural run-off or sewage effluent. *E. coli* infections are rarely associated with fish or shellfish, but one unusual outbreak in Japan illustrates that this is possible. In 1998, 62 cases of *E. coli* O157:H7 infection were reported in four separate locations after they ate salted salmon roe distributed to many Sushi shops.

Sushi and sashimi are a favorite food of many Chinese people, and are associated with fish products. These Japanese food items have a very short shelf-life. Bacterial contamination can come in various forms: *V. parahaemolyticus* is commonly found in seafood, whereas *S. aureus* and *Salmonella* species may be introduced into food by cross-contamination or improper handling during food processing. The best bet for bacterial prevention for most sushi and sashimi is to ensure that they arrive chilled on your plate and to polish them off quickly.

6.3.1.5 Milk and Dairy Products

Raw milk and dairy products often harbor a variety of microorganisms and are important sources of food-borne pathogens, such as *Salmonella*, *E. coli* and *Listeria*. Pasteurization is a process that kills harmful bacteria by heating milk to a specific temperature for a set period of time. However, entry of food-borne pathogens into dairy food processing plants via contaminated raw milk can lead to persistence of these pathogens in biofilms, and subsequent contamination of processed milk products and exposure of consumers to pathogenic bacteria. Furthermore, pathogens such as *L. monocytogenes* survive and thrive in post-pasteurization processing environments, thus leading to recontamination of dairy products.

6.3.2 Processing Methods

When we understand the characteristics and activity patterns of major food-borne pathogens, effective methods need to be established to control these pathogens and to reduce the risk of food-borne illness. In recent years, considerable progress has been made in the development of detection and control methods for food-borne pathogens in China.

Traditional thermal sterilization technology has been widely used in the food industry to prevent and reduce the growth of pathogenic bacteria. However, these methods usually lead to food quality deterioration. During rearing and storage of animal food ingredients, the main method to control the contamination of pathogens is the use of antibiotics, resulting in the formation of multidrug-resistant strains, which is a global health security risk. Moreover, food-borne pathogens can form biofilms, and exposure to sub-lethal conditions can help to protect the organisms from harsh environments and increase resistance to help survival, which brings forward an urgent need for new methods to control these pathogens. Therefore, programs are the needed to develop new bactericidal and bacteriostatic technology.

New sterilization methods through heat, such as ultra-high temperature (UHT) treatment, microwave sterilization and ohm sterilization, are rapid methods in microbiology. Furthermore, there are a lot of new non-thermal sterilization technologies, including ozone sterilization, UHP sterilization, pulsed electric field sterilization, ultraviolet disinfection, ultrasonic sterilization, irradiation sterilization and ultra-high static pressure cold sterilization. During these sterilization processes, the temperature rise is small or zero in order to preserve the original food nutrients, natural flavor and sensory characteristics.

Recently, a number of essential oils (EOs) and several of their individual components have exhibited antibacterial activity against food-borne pathogens *in vitro* and, to a lesser extent, in foods. The phenolic components are most active and appear to act principally as membrane permeabilizers. Moreover, the application of antagonistic microorganisms to solve the challenges of control of post-harvest diseases in fruits and vegetables is becoming increasingly popular worldwide. Although a lot more research is needed to make certain that microbial antagonists do not negatively influence the natural quality of fruits and vegetables, the use of antagonistic microbes is a promising alternative to synthetic chemical fungicides.

6.4 Prevention and Control of Bacterial Food Poisoning

6.4.1 Rapid Detection and Molecular Typing Methods

Conventional methods for the detection of food-borne bacteria are time-consuming and laborious, as they depend on the ability of the microorganisms to grow in different culture media, usually requiring two to three days for preliminary identification and a week for confirmation of the species of pathogen. Furthermore, conventional methods may be limited by their low sensitivity and false negative results for viable but non-culturable (VBNC) pathogens. The failure to detect food-borne pathogens would increase the transmission risk. Recently, researchers have developed novel methods with improvements in terms of rapidity, sensitivity, specificity and suitability for *in situ* analysis and distinction of the viable cell. Rapid methods are more time-efficient, labor-saving and able to reduce human error. Generally, rapid detection methods are categorized into nucleic-acid-based, biosensor-based and immunological-based methods [28]. The recent nucleic-acid-based methods described are simple polymerase chain reaction (PCR), multiplex PCR, real-time/quantitative PCR and microarray technology, which are sensitive and widely used for the detection of food-borne pathogens, but require trained personnel and specialized instruments. Alternative nucleic-acid-based methods such as nucleic-acid sequence-based amplification (NASBA) and loop-mediated isothermal amplification (LAMP) are available for the detection of food-borne pathogens and their toxins. NASBA and LAMP are relatively sensitive, specific and cost-efficient, and do not require a thermal cycling system, making them especially useful in low-resource settings. Biosensors that commonly used for the detection of food-borne pathogens are optical, electrochemical and mass-based biosensors. Biosensor-based methods are easy to operate and do not require trained personnel; furthermore, they can be used for the detection of food-borne pathogens without sample pre-enrichment. However, improvement in food matrix detection is still needed for these methods for on-site detection. Enzyme-linked immunosorbent assay (ELISA) and lateral flow immunoassay are among the immunological-based methods that have recently been used for the detection of food-borne pathogens and their toxins. Immunological methods work well in the absence of interfering molecules in the samples such as non-targeted cells, DNA or proteins. Rapid methods provide various advantages for the detection of food-borne pathogens, however they also have several limitations. Therefore, further studies on the effect of different combinations of rapid methods for food-borne pathogen detection are required in order to develop the most effective and accurate detection methods.

Multiple molecular typing technologies are available for bacterial source tracking, which are usually used to determine the distribution of pathogens and to link people who are ill after the consumption of contaminated foods. The molecular-based typing methods available fall into three general categories [29] based on these principals: (a) restriction analysis of the bacterial DNA, such as plasmid analysis, restriction fragment length polymorphism (RFLP) analysis, ribotyping and pulsed-field gel electrophoresis (PFGE); (b) polymerase chain reaction (PCR) amplification of particular genetic targets, such as amplified fragment length polymorphisms (AFLP), random amplified polymorphic DNA PCR (RAPD-PCR), repetitive element PCR (Rep-PCR) and multiple locus VNTR analysis (MLVA); (c) the identification of DNA sequence polymorphisms, such as multi-locus sequence typing (MLST) and single nucleotide polymorphism (SNP) analysis. Each of the techniques described has its advantages and disadvantages that affect its applications as a molecular typing tool for food-borne bacterial pathogens. In most cases, PFGE remains highly attractive since it is thought of as the gold standard for molecular sub-typing. However, some of the newer methods based on genomic information are potential alternatives for molecular typing. Often, MLVA, MLST and SNP analyses appear to perform as well or better than PFGE for sub-typing and require a shorter time, but they often need specialized equipment, such as an automated DNA sequencer. Furthermore, the choice of the appropriate molecular typing method will rely upon the epidemiological demand and the resources available for typing. If speed is important for a limited disease outbreak, a PCR-based method may work well for the characterization of these isolates. However, if a food-borne disease outbreak is widespread across multiple geographical areas, a more robust method, such as PFGE, will be needed to allow efficient sharing of the typing results generated in multiple laboratories. Each method has its limitations in identifying a specific strain, which may be missed, but may be found by another method. Therefore, in certain situations, a combination of typing methods may be required to separate non-clonal isolates.

6.5 Principles of Prevention and Control

6.5.1 Novel Physical Control Technologies

Conventional thermal processing has been used as an effective and economical technique for ensuring microbiological food safety in the food industry. However, it also affects the color, flavor and nutrition of the product. In recent years, to retain high-quality food, novel thermal processing and non-thermal processing have attracted extensive attention. Novel thermal processing limits the degree of heat to the smallest range, such as ultra-high temperature (UHT), microwave heating and ohmic heating, and has been developed to kill food-borne bacteria at the fastest speed to meet product indicators [30]. Some of the other physical methods and techniques, such as ozone processing, pulsed electric field (PEF), ultrasound processing, high hydrostatic pressure processing (HHP) and radiation processing, have been used as non-thermal sterilization technologies [31], by which the food temperature does not rise or rises very little in the sterilization process, which is helpful in retaining food nutrients and natural flavors.

6.5.2 Essential Oils as Antimicrobials

In recent years, aromatic plants and their extracts have been examined for their effectiveness in food safety and preservation applications, in which essential oils (EOs) and other secondary plant metabolite components have been used as alternatives for antimicrobials [32]. Phytochemicals, such as EOs, are naturally occurring antimicrobials found in many plants that have been shown to be effective in a variety of applications in killing and inhibiting microorganisms. Essential oils from different sources have been widely promoted for their potential capabilities against food-borne pathogens [33]. Synthetic chemicals are limited due to undesirable aspects, including carcinogenicity, acute toxicity, teratogenicity and slow degradation periods, which could lead to environmental pollution. The negative public perception of industrially synthesized food antimicrobials has generated interest in the use of more naturally occurring compounds.

6.5.3 Bacteriophages for Biocontrol of Food-borne Pathogens

Bacteriophages are bacterial viruses that only infect and multiply within their specific hosts. This specificity of phages allows them to directly target dangerous bacteria. The use of phages or phage products in food production has recently become an option for the food industry as a novel method for biocontrol of specific pathogens [34], enhancing the safety of especially fresh and ready-to-eat food products. Bacteriophage-based applications hold great promise in food safety; however, the selection of phages for use in products on the basis of their infective potential under laboratory conditions may not be the ideal approach [35]. It is important to understand how food-associated environmental conditions may impact the adsorption efficiency of phages used in a product.

6.5.4 Bacterial Biofilm Control in Food Environments

The capability of bacteria to colonize food processing surfaces and to form biofilms has become an emerging concern for the food industry. Biofilms develop and grow on processing equipment surfaces such as plastic, glass, stainless steel or rubber. The formation of a biofilm increases bacterial resistance to desiccation, ultraviolet, disinfectants and so on. Bacterial cells in biofilms are 100–1000 times more resistant to disinfectants than are planktonic cells [36]. Therefore, some conventional disinfectants cannot effectively sterilize bacteria in a biofilm state. Currently, chemical disinfectants, such as chlorine dioxide, sodium hypochlorite, ozone, hydrogen peroxide, and peracetic acid, have been mainly used in food factories for controlling biofilms. Higher temperature and a larger amount of disinfectants are needed to eliminate bacterial biofilms, but may reduce the nutritional value of food, and the disinfectant residue may also adversely affect the human body. Novel and alternative techniques, like antiquorum sensing, antibiofilms, enzymes, hurdle techniques and bacteriophages will significantly help to control the formation of biofilms for enhanced food safety [37].

6.5.5 Education of the Public to Reduce Food-borne Illness

Most cases of food-borne illness can be prevented with proper cooking or processing of food to destroy pathogens. Education of the general public and food handlers will enhance their understanding of safe food preparation and handling, especially for high-risk populations. Educational interventions are necessary to improve consumer food safety practices and reduce the associated food-borne illness. Right now, a few supermarket chains are promoting food safety by educating consumers to keep food safe at home, and working with the government to prevent contaminated food from entering the distribution system. It is helpful to use and evaluate food labelling to communicate safe food preparation and provide risk information on food choices to susceptible persons. Food handlers and consumers should know the food they use (read labels on food package, make an informed choice, become familiar with common food hazards), handle and prepare food safely, practicing the WHO Five Keys to safer food at home (keep clean; separate raw and cooked; cook thoroughly; keep food at safe temperatures; use safe water and raw materials) or when selling at restaurants or at local markets.

6.6 Future Aspects

6.6.1 Viable but Non-Culturable (VBNC) Bacteria

Under stress conditions, many species of bacteria enter into a starvation mode of metabolism or a physiologically viable but non-culturable (VBNC) state. Various stress factors during food processing and storage, such as sterilization, disinfectants and preservatives, may lead food-borne pathogens into a VBNC state. The pathogenic VBNC bacteria are considered a threat to public health and food safety due to their non-detectability using conventional culture media, but they continue to retain their viability and express their virulence [38]. Moreover, VBNC bacteria are an untapped microbial resource, and studies of its formation mechanism, potential function and application performance will become the focus of attention [39].

6.6.2 Horizontal Transfer of Antibiotic-Resistance by Mobile Genetic Elements

The prevalence of antimicrobial resistance among food-borne pathogens has increased during recent decades, possibly as the result of selection pressure created by the abuse of antimicrobials in food-producing processes. It might be a major threat to public health, as the antibiotic resistance determinants can be transferred to other bacteria of human clinical significance. Food-borne pathogens in raw food samples have been considered to be a pool of mobile genetic elements (MGEs) and the transfer of antibiotic resistance can readily occur between similar bacteria. The coexistence of resistance genes with mobile elements such as plasmids, transposons and integrons facilitates the rapid spread of antibiotic resistance genes among bacteria. Molecular analysis of antibiotic resistance genes and antibiotic-resistant mobile elements has become a research hotspot.

6.6.3 Applications of High-Throughput Omics Technology

The entire genome sequences of numerous food-borne pathogens have been determined, and genome sequencing projects of many others are currently underway. The resulting sequence information will permit detailed bioinformatics analyses and provide direction for subsequent functional analyses. Genomics-driven studies will have many applications in the control of food safety, such as assisting with the development of tools for the rapid detection and identification of pathogens and helping to provide insights into their evolution, biology and ecological fitness [40]. These studies will also aid in elucidating the mechanisms employed by pathogens as they adapt to the variety of conditions encountered throughout their life cycle, from the food-processing environment to *in vivo* during infection. It is anticipated that genomics will aid in the development of novel preventative and control strategies, which in turn will ultimately lead to a safer food supply.

6.7 Risk Assessment of Food-borne Pathogens

6.7.1 Microbiological Quantitative Risk Assessment

Since the middle of the 1990s, risk analysis (RA) has gained international acceptance as the most effective tool for managing microbiological hazards in food and has emerged as a structured model for improving food control systems with the objective of producing safer food, and for facing the increasing incidence of food-borne illnesses, as well as facilitating domestic and international trade in food. The definition of microbiological risk assessment could be interpreted in the broadest sense as any scientific research to estimate the likelihood and severity of risk with attendant uncertainty. Quantitative risk assessment is one of three components of RA; the others being risk management and risk communication. Quantitative risk characterization [41] is aimed at identifying both the confidence intervals associated with the risk estimates and the contribution that each step in a particular food pathway has on the risk level. Take, for example, the question of whether the reduction of antibiotic usage in agriculture reduces resistance in human pathogens. It was concluded that: (a) the reduction of antibiotic usage in agriculture most likely lowers resistance in a human health care setting, (b) the greatest risk for both *de novo* development and for transfer of resistance occurs with exposure to low concentrations of antibiotics and (c) the limited ecological range of resistant strains may be used to design “smart” measures.

Quantitative risk assessment, in particular when using stochastic models, is a specialized task that requires skills in mathematics and statistics in addition to microbiological and technological knowledge. As a consequence, risk assessments are usually conducted in large, multi-disciplinary projects. Building a comprehensive model may be resource intensive. The output of risk models is relatively complex, and in order to guide the risk assessment and interpret the results, risk managers need to understand the basic principles of modelling and concepts like uncertainty and variability. A general framework for doing quantitative microbiological risk assessment (QMRA) [42], the Modular Process Risk Model (MPRM) was recently proposed. The idea is that to each of the steps at the intermediary stages of a farm-to-fork chain at least one of six basic processes can be assigned, specifically, growth, inactivation, partitioning, mixing, removal and cross-contamination.

6.7.2 Examples of Modelling Exercises

6.7.2.1 A Shiga-Toxin-Producing Escherichia coli O157 in Steak Tartare Patties [43]

The hazard considered is Shiga-toxin-producing *E. coli* O157 (STEC O157), a notorious pathogen. Cattle are generally considered to be the most important reservoir of STEC O157. Therefore, a beef product was chosen as the food for which the risk was evaluated. Based on consumption frequency, potential risk and relative simplicity of processing, the product choice was "steak tartare patties," a lean ground beef product, typically eaten raw or partially raw. To limit the complexity of the assessment, only the Dutch population and only data on Dutch animals and slaughterhouses were considered in the analysis. Consumers were separated into three age classes, 1–4 years, 5–14 years and 15^+, to fit with the effect modelling. Next, three preparation styles for the steak tartare patties (raw, medium and well done) were considered. (Dutch) data were collected on the prevalence and concentration of STEC O157 at the different stages of the food pathway: farm, slaughter, retail and consumer. The exposure model predicted that about 0.3% of the raw steak tartare patties would be contaminated with STEC O157. Of these contaminated patties, a large fraction (>60%) would be contaminated with 1 CFU only. High contamination levels are rare, with, for example, only 7% of the contaminated raw steak tartare patties containing more than 10 CFU. In a microbiological survey it was found that 1 in 82 raw steak tartare patties (1.2%) was positive for STEC O157. Knowing that the probability of detection of single CFUs in such a survey is small, this suggests that the model prediction is an underestimation of the actual level of contamination of steak tartare patties.

6.7.2.2 Bacillus cereus in broccoli puree [44]

The Modular Process Risk Model (MPRM) methodology is illustrated in a case study, an exposure assessment of a spore-forming pathogen, *B. cereus*, in a refrigerated processed food of extended durability (REPFED): a package of broccoli puree. The level of exposure is highly influenced by consumer behavior. With the present knowledge (which is, among others, characterized by the lack of dose-response information), it was not possible to quantify the risk, or to draw any "certain" conclusions on the risk of the product. There is no dose-response relationship available for *B. cereus*. Based on epidemiological studies, a concentration of 10^5 CFU/g is generally considered a critical value. As an estimate, at the moment the consumer takes the product from the refrigerator there may be a probability up to 6.5% of dealing with a pack that contains more than 10^5 CFU/g, if contaminated with a psychotropic *B. cereus* strain. Controlling for food safety at the end of the industrial process by taking random samples there appears to be a bad predictor of food safety risk for the consumer.

6.7.2.3 Pathways to be Included in Risk Assessment of Campylobacter in Chickens [45]

A quantitative risk assessment for *C. jejuni* in whole, chilled or frozen chicken products in Denmark has been developed. To quantify the health risks attributed to *Campylobacter* contaminated chickens, two models were developed: one describing the transfer and spread of *Campylobacter* through a chicken slaughterhouse and another dealing with the transfer and spread of *Campylobacter* during food handling in private kitchens. Uncertainty and variability linked to the model parameters were included. By combining the two models, the effect of different mitigation strategies on the probability of exposure and illness could be analyzed. In particular, strategies that reduced the *Campylobacter* load on chickens seemed to have significant impact on the number of human cases. Cross-contamination from positive to negative flocks had almost no effect, which may indicate that logistic slaughter has a minor influence on the risk. Finally, the simulations showed that people aged 18–29 years had the highest risk of illness, a result that is in good agreement with current observations.

6.7.3 Assessment of the Microbiological Quality of Fresh Produce

Fresh produce occupies an increasingly important place in the human food supply because of its health-promoting nutritional properties. Most fresh produce is consumed raw or after minimal processing and, consequently, pathogen contamination can represent a serious health risk. *Salmonella*, *Shigella*, pathogenic *E. coli*, *L. monocytogenes* and *Campylobacter* are the most important vegetable-borne pathogens [46]. It is necessary to assess the hygienic quality and the prevalence of the most common bacterial pathogens in fresh produce, minimally processed vegetables (MPVs) and unprocessed vegetables (UVs), sold in retail markets. Some authors report *Salmonella* in less than 8% of the analyzed samples, *Campylobacter* in 3.1% of lettuce, but *E. coli* O157 in up to 25% of cabbages and 19.5% of coriander and *L. monocytogenes* in up to 7% of cabbages, 22.7% of leafy vegetables and 20% of lettuce. Other reports describe prevalence lower than 1–2% for *E. coli* O157, *Campylobacter* and *Salmonella*. Even though there are worldwide reports of outbreaks associated with the consumption of vegetable products, data concerning the microbial contamination level of these foodstuffs are still few and discrepant; in particular, this lack of knowledge affects most MPV and UV vegetables. Although *E. coli* and *L. monocytogenes*/*Salmonella* were defined as microbiological criteria for process hygiene and food safety, respectively, there is no further specific regulation for other food-borne pathogens (e.g. *Yersinia*, *Campylobacter*) and for other types of vegetable products (e.g. MPVs and UVs). It is necessary to implement strategies to increase the microbial safety of fresh produce.

References

1 Bai C, Huang Y. (2014) *Essentials of Food Safety and Hygiene*. Beijing: China Light Industry Press. pp. 21–36. [In Chinese]

2 Fang H, Chen C. (2014) *Bacteria of Food Poisoning in China*. Beijing: Science Press. pp. 3–24. [In Chinese]

3 Li F, Wang Y. (2014) *Food Nutrition and Hygiene*. Beijing: Chemical Industry Press. pp. 242–248. [In Chinese]

4 Yang B, Qu D, Zhang X, *et al.* (2010) Prevalence and characterization of *Salmonella* serovars in retail meats of marketplace in Shaanxi, China. *Int J Food Microbiol.* 141(1–2):63–72.

5 Wang S, Duan H, Zhang W, *et al.* (2007) Analysis of bacterial foodborne disease outbreaks in China between 1994 and 2005. *FEMS Immun Med Microbiol.* 51:8–13

6 Gao T. (2003) Research advance on *Staphylococcus aureus* enterotoxin and its detection methods in Food. *Fujian Analysis and Testing.* 12(2):1775–1781. [In Chinese]

7 Luo L, Wang X, Liu J, *et al.* (2010) Investigation and analysis on the contamination and drug resistance for *listeria* in some commercially available agricultural by-products in Minhang district of Shanghai. *Modern Prevent Med.* 37(22):4302–4303. [In Chinese]

8 Mao X. (2010) The study on epidemiological characteristics and disease burden of bacterial foodborne disease in China, during 2003–2008. Beijing: The Chinese Center for Disease Control and Prevention. Dissertation thesis. [In Chinese].

9 Zhao H, Fu L, Tang G. (2012) Main foodborne pathogens in our country. *J Med Pest Control.* 28(11):1212–1215. [In Chinese]

10 Guibourdenche M, Roggentin P, Mikoleit M, *et al.* (2010) Supplement 2003–2007 (No. 47) to the White-Kauffmann-Le Minor scheme. *Res Microbiol.* 161(1):26–29.

11 Zhang H. (2002) *Salmonella* classification, nomenclature and its serotype distribution of China. *Prog Microbiol Immun.* 2:74–76. [In Chinese]

12 Li Y, Ju Y, Wang X, *et al.* (2007) Study on the inhibition of Chinese traditional compound medicine "LN" to Salmonellosis. *Jilin Animal Hus Vet Med.* 234(28):9–11. [In Chinese]

13 Mąkaa L, Maćkiwa E, Ścieżyńskaa H, *et al.* (2014) Antimicrobial susceptibility of *Salmonella* strains isolated from retailmeat products in Poland between 2008 and 2012. *Food Control.* 36(1):199–204.

14 Liu X, Chen Y, Wang X, *et al.* (2004) Foodborne disease outbreaks in China from 1992 to 2001 national foodborne disease surveillance system. *J Hygiene Res.* 33(6):725–727. [In Chinese].

15 Garrido A, Chapela M, Ferreira M, *et al.* (2012) Development of a multiplex real-time PCR method for pathogenic *Vibrio parahaemolyticus* detection (tdh$^+$and trh$^+$). *Food Control.* 24:128–135.

16 Chen W, Zheng L, Wu J, *et al.* (2011) The discussion about how to increase the detection rate of *Vibrio parahaemolyticus* in food. *Chin J Health Lab Technol.* 7(21):1718–1721. [In Chinese]

17 Tang J, Zhou R, Shi X, *et al.* (2008) Two thermostable nucleases coexisted in *Staphylococcus aureus*: evidence from mutagenesis and in vitro expression. *FEMS Microbial Lett.* 284(2):176–183.

18 Hvistendahl M. (2012) China takes aim at rampant antibiotic resistance. *Science.* 336(6083):795.

19 Dongou L. (2008) *Handbook of Listeria monocytogenes*. London, UK: CRC Press: 3–27.

20 Hong Kong Food and Environmental Hygiene Department. (2014) Hong Kong Food Microbiological Guidelines [S]. [In Chinese].

21 GB 29921-2013 National Food Safety Standards of Food Pathogens Limit [S]. (2013) [In Chinese].

22 Jin T, Ma F, Yuan Y. (2013) Rapid detection of *E. coli* O157:H7 by immunocapture and loop-mediated isothermal amplification. *Food Sci Technol.* 38(8):318–322. [In Chinese]

23 Dikici A, Koluman A, Calicioglu M. (2015) Comparison of effects of mild heat combined with lactic acid on Shiga toxin producing *Escherichia coli* O157:H7, O103, O111, O145 and O26 inoculated to spinach and soybean sprout. *Food Control.* 50:184–189.

24 Snedeker KG, Shaw DJ, Locking ME. (2009) Primary and secondary cases in Escherichia coli O157 outbreaks: a statistical analysis. *BMC Infect Dis.* 9:144.

25 Wang T, Liu L, Wang P, *et al.* (2010) Virulent genes of *Escherichia coli* O157:H7 strains isolated from China. *Chin J Zoonoses.* 26(6):515–518. [In Chinese]

26 Zhao S, Li X, Cao X, *et al.* (2013) Progress in research on *Bacillus botulinus* and botulinum toxins. *Chin J Animal Quarant.* 30(8):36–40. [In Chinese]

27 Liu J, Jiang T, Chen L. Progress Botox measurement and control technology. *Botulinum Column*. 14:7–10. [In Chinese]

28 Law JW, Ab Mutalib NS, Chan KG, *et al.* (2015) Rapid methods for the detection of foodborne bacterial pathogens: principles, applications, advantages and limitations. *Front Microbiol.* 5:770.

29 Foley SL, Lynne AM, Nayak R. (2009) Molecular typing methodologies for microbial source tracking and epidemiological investigations of Gram-negative bacterial foodborne pathogens. *Infect Genet Evol.* 9(4):430–440.

30 Li M, Li J, He X, *et al.* (2013) Thermal and non-thermal sterilization technologies in food processing. *Acad Period Farm Prod Process.* 8:110–113. [In Chinese]

31 Wu Y. (2015) Application of non-thermal sterilization technology in food processing. *J Anhui Agri Sci.* 43(1):242–243. [In Chinese]

32 Calo JR, Crandall PG, O'Bryan CA, *et al.* (2015) Essential oils as antimicrobials in food systems: A review. *Food Control.* 54:111–119.

33 Friedman M. (2015) Antibiotic-resistant bacteria: prevalence in food and inactivation by food-compatible compounds and plant extracts. *J Agric Food Chem.* 63(15):3805–3822.

34 Singh A, Poshtiban S, Evoy S. (2013) Recent advances in bacteriophage based biosensors for food-borne pathogen detection. *Sensors (Basel).* 13(2):1763–1786.

35 Denes T, Wiedmann M. (2014) Environmental responses and phage susceptibility in foodborne pathogens: implications for improving applications in food safety. *Curr Opin Biotechnol.* 26:45–49.

36 Jahid IK, Ha SD. (2012) A review of microbial biofilms of produce: Future challenge to food safety. *Food Sci Biotechnol.* 21 (2):299–316.

37 Simoes M, Simoes LC, Vieira MJ. (2010) A review of current and emergent biofilm control strategies. *LWT Food Sci Technol.* 43(4):573–583.

38 Ding L, Su X, Yokata A. Research progress of VBNC bacteria: A review. *Acta Microbiol Sinica*. 51(7):858–862.

39 Ramamurthy T, Ghosh A, Pazhani GP, *et al.* (2014) Current perspectives on viable but non-culturable (VBNC) pathogenic bacteria. *Front Public Health.* 2:103.

40 Wiedmann M and Zhang W. (2011) *Genomics of Foodborne Bacterial Pathogens.* New York: Springer-Verlag New York Inc.

41 Giaccone V, Ferri M. (2005) Microbiological quantitative risk assessment and food safety: an update. *Vet Res Commun. Suppl* 2:101–106.

42 Romero-Barrios P, Hempen M, Messens W, *et al.* (2013) Quantitative microbiological risk assessment (QMRA) of food-borne zoonoses at the European level. *Food Control* 29:343–349.

43 Nauta M, Evers E, Takumi K, Havelaar A. (2001) Risk assessment of Shiga-toxin producing *Escherichia coli* O157 in steak tartare in the Netherlands. Bilthoven: National Institute for Public Health and the Environment. Report no. 257851 003.

44 Nauta M. (2000) Separation of uncertainty and variability in quantitative microbial risk assessment models. *Int J Food Microbiol.* 57: 9–18.

45 Christensen B, Sommer H, Rosenquist H, *et al.* (2001) Risk assessment on *Campylobacter jejuni* in chicken products. Danish Veterinary and Food Administration, Ministry of Food Agriculture and Fisheries.

46 Cardamone C, Aleo A, Mammina C, *et al.* (2015) Assessment of the microbiological quality of fresh produce on sale in Sicily, Italy: preliminary results. *J Biol Res (Thessalon)*. 22(1):3.

7

Mycotoxins in China: Occurrence and Exposure

Yunyun Gong[1]*, Fengqin Li*[2] *and Michael N. Routledge*[3]

[1] *School of Food Science and Nutrition, University of Leeds, UK*
[2] *China National Center for Food Safety Risk Assessment, Beijing, China*
[3] *School of Medicine, University of Leeds, UK*

7.1 Introduction to Mycotoxins

Mycotoxins are secondary metabolites produced by a variety of fungi, which can contaminate crops used in the production of human food and animal feed, leading to health risks to humans. Economic impacts of mycotoxins, through loss of trade, restriction of export of contaminated crops and by reduction in yield of agricultural animals fed contaminated feed, are significant. Mycotoxins of concern to human health include aflatoxins, fumonisins (FB), deoxynivalenol (DON) and zearalenone (ZEN), ochratoxin A, T-2 mycotoxin, patulin and citrinin. Whilst contamination of crops by mycotoxin-producing fungi usually occurs in the field, in some cases the growth of the fungus and the production of the toxin are enhanced by storage in warm, humid conditions. As a large agricultural production and exportation country with climatic conditions in various regions that are favorable to different types of mycotoxin-producing fungal growth, China is inevitably affected by mycotoxin occurrence with many large mycotoxin outbreaks in the country's history. The great diversity in climate and ecological conditions, together with multiple cultural practices, and variations in rates of economic development across China contribute to large differences in mycotoxin occurrence and exposure. Although China has made serious efforts to minimize mycotoxins entering the food chain, and mycotoxin exposure has decreased in parts of China such as Qidong that had historically high aflatoxin exposure, the recent discovery of higher than permitted levels of aflatoxin M_1 in dairy products has raised food safety concerns and caused alarm nationwide. In this chapter we will focus on five key mycotoxins of concern, aflatoxins, FB, DON, T-2 toxin and ZEN. Although high levels of exposure of these toxins are known to cause acute toxicity in humans and/or animals, the strongest association between chronic exposure and human health risk is that of aflatoxin and primary hepatocellular carcinoma (HCC) and the evidence for this association in China will be discussed in depth. We will summarize the current evidence regarding mycotoxin occurrence and exposure in China, the health risks associated with these mycotoxins and review the advances of China's regulatory policy and management.

Food Safety in China: Science, Technology, Management and Regulation, First Edition.
Edited by Joseph J. Jen and Junshi Chen.

7.2 Aflatoxin

7.2.1 Introduction

Aflatoxins are mycotoxins produced by *Aspergillus* section Flavi. *Aspergillus* species are found in soil across a wide geographic distribution (at temperatures between 24 °C and 35 °C with 7–10% relative humidity) with crops being particularly susceptible to contamination during periods of drought [1]. Fungal contamination and toxin production can occur before harvest and continue to increase post-harvest under hot and humid conditions. Contamination in the field often happens as a result of insect damage and lack of irrigation, but storage practices can affect fungal growth and aflatoxin production post-harvest. Techniques, including proper drying of grains, improved ventilation at storage, hand-sorting of moldy grains and pesticide usage have proved to be effective in aflatoxin reduction at the post-harvest stage.

Of the four main types of aflatoxin found in food – aflatoxin B_1 (AFB_1), aflatoxin B_2 (AFB_2), aflatoxin G_1 (AFG_1) and aflatoxin G_2 (AFG_2) – AFB_1 is the most prevalent, the most toxic and is a human carcinogen. The exact ratio of aflatoxins present will vary, as this can be dependent on the strain of fungus contaminating the particular crop.

Aflatoxin M_1 (AFM_1) is a hydroxylated metabolite of AFB_1 that can be excreted from milk and urine after ingestion of AFB_1-contaminated food/feed. AFM_1 is a possible human carcinogen, and exhibits similar types of toxicity as AFB_1 but is less potent. Animals exposed to AFB_1 can also be a source of exposure to aflatoxins, primarily in the form of AFM_1 in milk, although a small amount of AFM_1 can be found in tissues such as muscle, kidney and liver. It is estimated that 1–2% of AFB_1 intake from contaminated feed can be excreted in milk in the form of AFM_1. Although not as toxic as AFB_1, the presence of AFM_1 in milk is of concern because of the potential exposure of children.

7.2.2 Methods for Detection of Aflatoxin

The China national standard (GB) methods for aflatoxin detection include GB/T 18979-2003 Immunoaffinity clean-up with high performance liquid chromatography (HPLC) and/or fluorescent spectrometry analysis of aflatoxins in food, GB/T 5009.23-2006 Aflatoxin B_1, B_2, G_1, G_2 in food analytical method, GB/T 23212-2008 Aflatoxin B_1, B_2, G_1, G_2, M_1, M_2 in milk and milk powder liquid chromatography with post-column fluorescence derivatization (LC-FLD) analytical method and GB/T 17480-2008 Feed aflatoxin B_1 ELISA detection method. GB/T 18979-2003 applies to maize, peanuts and products, rice, wheat, plant oil, soya sauce and vinegar. The limit of detection (LOD) for both HPLC with fluorescent spectrometry and the LC-FLD methods is 1 μg/kg for B_1, B_2, G_1 and G_2 except for soya sauce, where the LOD is 2.5 μg/kg. GB/T 5009.23-2006 includes thin layer chromatography (TLC), mini-column screening and HPLC methods. The first two methods can be used for all food aflatoxin B_1, B_2, G_1 and G_2 detection, with the LOD for aflatoxin B_1 and G_1 at 5 μg/kg, B_2 and G_2 at 2.5 μg/kg; the third method can be used for rice, maize, peanut, almond, walnuts and pine nuts, with the LOD for aflatoxin B_1 and G_1 at 0.20 μg/kg, and B_2 and G_2 at 0.05 μg/kg. GB/T 23212-2008 for aflatoxin B_1, B_2, G_1, G_2, M_1, M_2 with the LODs in milk being 0.002, 0.001, 0.003, 0.003, 0.005, 0.005 μg/kg, respectively, and in milk powder 0.02, 0.01, 0.03, 0.03, 0.05, 0.05 μg/kg, respectively. GB/T 17480-2008 can be used for feed, and mixed and concentrated feed with the LOD at 0.1 μg/kg.

7.2.3 Measurement of Exposure to Aflatoxin

Because aflatoxin contamination of crops such as maize and peanuts is often heterogeneous, the contamination measurement is liable to large sampling error. This has led to the development of several biomarkers to measure aflatoxin exposure in individuals. The most commonly used are the urinary AFB_1 N^7-guanine adduct, which is a product of DNA repair, the aflatoxin albumin adduct (AF-alb) in serum and the metabolite AFM_1 in urine or milk [2]. Using biomarkers to assess exposure improves exposure monitoring as the levels of biomarkers more accurately reflect individual intake of aflatoxins. Application of these biomarkers has been invaluable in understanding variation in exposure levels in different populations and across different time periods (including seasonal variation) as well as in elucidating the health effects of aflatoxin or monitoring success of interventions to reduce exposure.

7.2.4 Toxicity of Aflatoxins

Aflatoxin is highly toxic to both animals and humans. Acute exposure of humans to high levels of aflatoxin can lead to fatal liver damage, and events of this nature occur periodically, especially in Africa. One of the most severe reported outbreaks of acute aflatoxicosis occurred in Kenya in 2004, with 125 deaths out of 317 cases of acute liver failure. Samples of maize from the affected area were found to be contaminated with up to 4400 ppb aflatoxin and it was estimated that exposure levels between 29 and 117 μg/kg body weight could be fatal, with variation depending on individual susceptibility [3]. Lower levels of chronic exposure are associated with chronic aflatoxicosis, of which the risk of HCC is the most critical.

Primary HCC is recognized as one of the main risks associated with chronic exposure to aflatoxin in the diet. The epidemiological evidence that aflatoxin is a human liver carcinogen is very strong and aflatoxin has been classified as a known human carcinogen by the IARC. Historically, China was one of the highest aflatoxin exposure risk countries in the world. Some regions of China are particularly prone to aflatoxin due to the climate and geographical location, for example in Jiangsu, Guangxi and Taiwan. All have been repeatedly reported to have a high frequency of high aflatoxin contamination of food, as well as a high incidence of HCC [4–8]. A series of epidemiology studies on aflatoxins and HCC risk were conducted in China. Ross *et al.* [9] demonstrated a strong synergistic effect between aflatoxin exposure and hepatitis B virus (HBV) on HCC risk in a Shanghai cohort. A study in Taiwan also showed that aflatoxin exposure was enhancing the risk of HCC associated with HBV [8]. A more recent study in Taiwan suggested that the combined effect of aflatoxin and HBV was additive rather than multiplicative [10]. In Guangxi a positive correlation between HCC mortality and AFB_1 intake from maize and peanut oil, but not from rice, was reported (5,6). Assessing aflatoxin exposure by detecting urinary AFM_1 from HBV-positive subjects in Guangxi from eight, monthly, collections before the initiation of follow-up, an increase in HCC risk of 3.3-fold was reported in those with detectable AFM_1. A study of residents from Fusui ($N = 89$, HCC mortality rate 92–97/100,000) and Nanning ($N = 196$, 32–47/100,000) of Guangxi Province and Chengdu ($N = 118$, 21/100,000) of Sichuan Province reported a significant and independent effect of AFB_1 exposure, as measured by urinary AFB_1 metabolites, on HCC risk (OR, 4.29) among non-carriers [11]. In Qidong, a 21-year longitudinal study reported that when urinary AFM_1 was >100 ng/day, the HCC incidence increased from a rate of 1251 per 100,000 person years in non-exposed individuals to 4718 per 100,000 person years [12].

Most of the more severe exposures took place prior to 1990. During the last 30 years, changes in China have led to a significant drop in maize intake, and hence a drop in the risk of aflatoxin exposure. As a result of both this and the nationwide HBV vaccination policy over the same period, the prevalence of HCC in young populations has dropped significantly, according to recent cancer registration data. In Qidong, one of the highest prevalence regions, HCC mortality had shown more than 50% reduction between the 1960s and the 1980s generations. This is thought to be attributable to the reduction of aflatoxin exposure through diet pattern changes from maize to rice and wheat in the last three decades, as evidenced by the AF-alb median level changing from 19.3 pg/mg albumin in 1989 to undetectable (<0.5 pg/mg) by 2009. Furthermore, HBV vaccination of newborn babies has been a nationwide program since the 1980s, and an 83% reduction in HCC mortality has been attributed to this in the corresponding population group [13].

Utilizing the mathematics model of the Joint FAO/WHO Expert Committee on Food Additives (JECFA) and the HBV detection data in China in 2004, Wang *et al.* [14] conducted a mathematical model evaluation of the risk of HCC attributed to dietary aflatoxin exposure in the Chinese population. At an average level of aflatoxin exposure (665 ng/day), HCC incidence rate was estimated at 0.4 per 100 000 person years. At the 97.5 percentile (24,787 ng/day) the rate is 15 per 100 000 person years. When the margin of exposure (MOE) method was applied, at the national, urban and rural levels, based on the consumption data from the 4th Nationwide Nutrition Survey and contamination data from the National Surveillance Network (aflatoxin exposure average of 11, 8, 12 ng/kg bw per day), the MOE values were 9017, 12 304 and 8006, respectively; at the 97.5 percentile (412 289 and 489 ng/kg bw per day), the MOE values were 242 346 and 204, respectively. HCC risk for the Chinese population is moderate at the average exposure level, but high exposure consumers could have increased HCC risk.

There is evidence that exposure to aflatoxins in early childhood is associated with growth impairment in children. Cross-sectional and longitudinal studies in sub-Saharan Africa have suggested that aflatoxin exposure *in utero* and in early childhood can impair growth [15–17]. Possible mechanisms for the effects of aflatoxins on growth include: (a) aflatoxin liver toxicity leading to reduced levels of circulating insulin-like growth factor, which results in slowed growth [18], (b) compromised immune function by aflatoxin exposure leading to an increased risk of infectious disease, e.g., diarrhea, resulting in poor nutrition bioavailability.

Recently, the IARC reviewed the evidence for aflatoxin's adverse effects on child growth and immune function, highlighted that these health risks potentially impact millions of children in the developing world. There is evidence from several species that aflatoxins can modulate immune response and result in increased infection. Few studies have yet been carried out in humans. In Gambian children, dietary aflatoxin was associated with a reduction in secretory IgA in saliva [17] and certain subsets of cytotoxic T cells and B cells were reduced in Ghanaian adults with high AF-alb versus those with lower AF-alb [19]. Immunosuppression by aflatoxins in the diet, especially in children, could be an important cause of increased morbidity in exposed populations, but more research is needed in this area.

7.2.5 Occurrence of Aflatoxins in China

Historically, certain areas of China have seen a high frequency of aflatoxin contamination of maize, which led to high exposure levels where maize was the staple food crop. In 2001, concentrations of aflatoxin up to 2496 μg/kg were detected in Guangxi province, which is an area at high risk for primary liver cancer [20]. Following China's economic and agricultural reforms, maize is no longer the staple food for the majority of Chinese. Agriculture practices and grain storage conditions have also been significantly improved. These have all contributed to a significant shift of patterns in mycotoxin risk, but little is known about the current exposure level.

A recent survey of mycotoxin occurrence in the Yangtze Delta region of China reported around 14% of samples to be contaminated with a mean level of 6.9 μg/kg (range 1.1–35.0 μg/kg) [21]. The occurrence of aflatoxin in maize is found to be higher in the southern part than the northern part of China [22, 23], largely due to the high temperature and humidity in tropical and semi-tropical Southern China.

Peanuts are also susceptible to aflatoxin contamination. In 2007, Wang and Liu surveyed crops in six southern and eastern provinces and reported 23% of peanuts to be contaminated with AFB_1, mainly at low levels (mean 0.82, highest 1098 μg/kg) [24]. More recently, a two-year survey of over 1000 samples from the main peanut production area of China reported 95% of samples having <1 μg/kg aflatoxin, with only ten samples above the maximum limit (ML) of 20 μg/kg [25]. Other nuts, soybeans, seeds and seed oil, can also be contaminated. Rice and wheat are typically less affected by aflatoxin. Recently, low levels of aflatoxins were detected in ginger and lotus seeds, but levels up to 26 μg/kg were found in liquorice root samples [26].

Ma *et al.* analyzed 215, 125 and 292 maize, wheat flour and peanut samples, respectively, from 12 provinces/autonomous regions in 2010 using a multi-mycotoxin liquid chromatography-mass spectrometry (LC-MS) analytical approach [23]. Aflatoxins were detected in 53% and 40% of maize and peanut samples, respectively; 12 out of the 215 maize samples and 5 out of the 292 peanut samples were contaminated with AFB_1 above the ML. Samples from Yunnan and Guangxi in the south west of the country had the highest levels of AFB_1 contamination. Gao *et al.* reported that 76% of maize samples from six provinces were detected to contain aflatoxin with levels up to 888 μg/kg.

AFB_1 was also detected in 41 out of 50 peanut butter samples at up to 68.51 μg/kg, and in 37 out of 100 sesame paste samples, at up to 20.45 μg/kg; 37% and 2% of the peanut butter, and 37% and 12% of the sesame paste samples, exceeded the EU and Chinese MLs, respectively, meaning that 10–20% of these samples can be legally rejected and banned from import by the EU. The economic impact of this is significant [27].

7.3 Fumonisins

7.3.1 Introduction

Fumonisins are a family of mycotoxins produced primarily by the fungi *Fusarium verticillioides* (previously known as *F. moniliforme*), and *F. proliferatum* of the *Fusarium fujikuroi* species complex, and which mainly contaminate maize in the field, but can also contaminate wheat, barley and oats; to a lesser extent, fruit may be contaminated by fumonisins produced by *Aspergillus niger*. Whilst a number of types of fumonisins have been isolated, Fumonisin B_1 (FB_1), B_2 (FB_2), B_3 (FB_3) are most commonly detected in maize, and FB_1 is recognized as the most toxic and as possibly carcinogenic to humans. Fumonisins exhibit liver and kidney toxicity in animal experiments. The JECFA evaluated fumonisins and decided the provisional maximum tolerable daily intake (PMTDI) should be 2 μg/kg body weight for FB_1 or FB_1, FB_2 and FB_3 combined [28]. It has since been reported to be of high occurrence in South Africa, China, Iran and other countries [29]. Levels of contamination of maize by fumonisins vary from undetectable to 10 ppm in the USA to above 100 ppm in South Africa and even higher in parts of China.

7.3.2 Methods of Detection of Fumonisins

The national fumonisins standards include GB/T 25228-2010 Immunoaffinity column (IAC) purification and HPLC and FLD detection of fumonisins in food, oil and maize and products, NY/T 1970-2010 Feed fumonisin detection method, SN/T 1572-2005 Fumonisin HPLC detection method for food and feed for export and import. GB/T 25228-2010 is used for maize and maize products with the LOD at 0.1 mg/kg for the HPLC method and 0.5 mg/kg for the FLD method. NY/T 1970-2010 is the LC/MS or HPLC method, with the LOD at 0.01 mg/kg. SN/T 1572-2005 is for testing of grains for export and import with the LOD at 0.05 mg/kg for both FB_1 and FB_2.

More recently, LC-MS methods have been increasingly applied to fumonisin detection, giving better accuracy and more clear separation of the species.

7.3.3 Measurement of Exposure to Fumonisins

FB_1 inhibits sphinganine N-acyltransferase activity and the metabolism of sphingolipid due to the structural similarity of FB_1 to the sphingolipid. An increase in the sphinganine:sphingosine (Sa:So) ratio in urine or serum as a potential biomarker has been studied in China. A one-month monitoring study in China suggested that the urinary Sa:So ratio may be useful for evaluating FB_1 exposure when the contamination of FB_1 is high; however, the huge difference in sensitivity between genders held back the application of this approach. The biomarker was also found to show a lack of sensitivity for human exposure evaluation in studies from other countries [30].

Recently, urinary FB_1 has been proposed as a useful biomarker of exposure to fumonisin [31]. The urinary FB_1 biomarker has been examined in China, together with the urinary Sa:So ratio in a cross-sectional study of 43 adults from Huaian and 34 from Fusui. Based on dietary intake estimates, more of the Huaian adults than the Fusui adults (93% vs 53%) consumed FB_1 at levels above the PMTDI of 2 μg/kg body weight/day. Urinary sphinganine, sphingosine and the Sa:So ratio were not correlated with dietary FB exposure. The urinary FB_1 median level in Huaian subjects was significantly higher than that found in Fusui subjects (3.9 vs 0.39 ng/mg creatinine, $p < 0.01$).

Several studies have set out to investigate fumonisin occurrence and its relation to human cancers in China. Most of these are ecological studies, where maize samples from a high cancer risk region are compared to those of a low risk region [32–34]. Whilst these types of studies indicate a link between exposure and a specific type of cancer, it does not provide evidence for a causal relationship. A nested case control study in Linxian did not find a significant association between serum sphingosine, sphinganine or the Sa:So ratio and oesophageal cancer in 98 cases and 185 matched controls [35].

Because maize is the primary source of fumonisin exposure, the consumption level of maize determines the exposure severity in a population. Although data on fumonisins exposure in China is limited, the diminishing intake of maize in the Chinese diet in recent decades means that fumonisin exposure is expected to pose a relatively low risk to public health. However, it is worth noting that maize constitutes a large portion of animal feed in China. Farm animal exposure to fumonisins can be severe and thus carry-over effects from animals to humans is of justifiable concern.

7.3.4 Toxicity of Fumonisins

FB_1 causes equine leukoencephalomalacia and porcine pulmonary edema and is a rat kidney carcinogen and mouse liver carcinogen. In humans, FB_1 has been associated with neural tube defects, and exposure to FB_1 has been shown to be high in certain areas with high incidences of oesophageal and liver cancer [32–34]. However, a causative association between FB_1 and human cancer is yet to be established.

7.3.5 Occurrence of Fumonisins in China

One of the earliest published sets of data from China was from the study of FB, aflatoxin and trichothecenes in Cixian and Linxian – two regions with a high prevalence of oesophageal cancer. Higher levels of fumonisins and trichothecenes were found in moldy maize than non-moldy maize. A comparison of fumonisin occurrence in Gansu, Shandon, Ningxia and Inner Mongolia reported that Shandong (81% with detectable FB_1, mean 2496 μg/kg) had the highest occurrence amongst the four northern provinces. Overall average estimated exposure to fumonisins (0.12 μg/kg body weight/day) was below the PMTDI of 2 μg/kg body weight/day [36]. However, another study of 255 samples from major maize-producing provinces (Liaoning, Shandong and Henan) found maize samples from Liaoning in North West China had much higher contamination than those of Shandong and Henan, and the probable daily intake of fumonisins was 0.3 μg/kg of body weight [37]. In another study [38], higher fumonisin contamination was found in Yunnan from South West China.

More recently, fumonisins were detected using LC-MS in 98% of the 522 maize samples from Shandong, average 369.2 μg/kg, FB_1 268.3, FB_2 53.7 and FB_3 47.2 μg/kg, respectively, with simultaneous occurrence in 76.7% of the samples, but none were detected in maize oil [39]. Fumonisins were detected in 95% of maize samples in Hebei, at a similar level of 441 μg/kg ($FB_1 + FB_2 + FB_3$), whilst levels in wheat flour were low [40]. There have been reports that fumonisins can be detected in rice, spices, herbs and Chinese medicine [26].

7.4 DON

7.4.1 Introduction

DON, which is produced by *F. graminearum, Gibberella zeae* and *F. culmorum*, is the most frequently detected mycotoxin in cereals in China and many parts of the world. These fungi cause wheat head blight and maize ear rot disease, and reduce crop productivity. The occurrence is high when wheat flowers during high relative humidity and persistent rainfall, with high humidity being most important. DON is heat stable at 120 °C and can persist in cooked food.

7.4.2 Methods of Detection of DON

The analysis of DON primarily includes extraction, purification, derivatization if necessary, isolation and quantification. Liquid–liquid extraction is most commonly used for food. Enzyme-linked immunosorbent assay (ELISA), thin layer chromatography (TLC), HPLC, LC-MS or gas chromatography-mass spectrometry (GC-MS) analytical methods can then be used to measure DON and metabolites, with HPLC and LC-MS most commonly used due to high sensitivity and reliability. The national standard detection methods for DON include GB/T 5009.111-2003 DON analytical method in cereals and cereal products, GB/T 23503-2009 IAC and TLC-HPLC method for food DON analysis and SN/T 1571-2005 HPLC method for DON analysis in crops and cereals for import and export. The TLC and ELISA method LODs are 0.1 mg/kg and 0.1 ng/kg, respectively, in the GB/T 5009.111-2003, suitable for cereal and products detection, whilst GB/T 23503-2009 using IAC and TLC-HPLC method is suitable for detection in various foods. The LOD is 0.5 mg/kg for food and food products, and 0.1 mg/kg for alcohol, soya source, vinegar etc. SN/T 1571-2005 has the LOD at 0.04 mg/kg, primarily for exportation and importation detection.

7.4.3 Measurement of DON Exposure

A biomarker for DON exposure, namely, urinary DON and DON-glucuronides quantification, which involves glucuronidase digestion, and IAC purification with HPLC detection has been developed [41]. In a pilot survey of samples collected in 1997 and 1998 in the Shanghai women's study, 97% of samples contained the DON biomarker, although levels were lower than had previously been measured in the UK, reflecting the lower wheat intake in the diet in China [42].

7.4.4 Toxicity of DON

Numerous studies show that high doses of DON may cause animal death, while different exposure routes result in different LD_{50} levels. DON in the feed of farm animals leads to reduced growth, and at high levels induces vomiting. Pigs are most sensitive, with the minimum vomiting dosage for females being 100 mg/kg by oral administration. The no-observed-adverse-effect level (NOAEL) is 25 μg/ kg, whilst feed containing 12 mg/kg of DON can lead to complete feed refusal. No carcinogenicity has been reported for DON [43].

The JECFA [43] in 2010 set a group PMTDI of 1 μg/kg bw per day for DON and its metabolites, 3-acetylated-DON (3-Ac-DON) and 15-acetylated-DON (15-Ac-DON). A group acute reference dose (ARfD) of 8 μg/kg bw for DON and its metabolites was also established.

Human poisoning outbreaks due to trichothecene mycotoxins have mainly occurred in the old Soviet Union, China and India. There were 15 outbreaks reported in Henan, Guangxi, Hebei, Anhui and Jiangsu in China between 1985 and 1992, involving a total of 137 112 people suffering from DON-related poisoning caused by wheat scab or moldy maize [44]. In the spring and summer of 1991, many provinces in China suffered from severe floods in the wheat harvest season, with Anhui, Jiangsu and Henan provinces being the worst affected. As a result, large amounts of wheat became moldy. Residents in the affected areas suffered from acute poisoning following ingestion of moldy wheat. In Anhui province, 130,000 people reported poisoning. The major symptoms were dizziness, nausea, vomiting, abdominal pain, diarrhea and fatigue. According to data from the Institute for Nutrition and Food Safety, China CDC, high levels of DON were detected in the samples causing poisoning [45]. The mean DON level was 7044 μg/kg (max. 51 450 μg/kg) from the samples collected in Anhui province, where 42% of samples exceeded the current ML for DON in China at 1000 μg/kg. To date, there has been no evidence of adverse human health effects in relation to chronic exposure to DON.

7.4.5 Occurrence of DON in China

Studies have shown that DON contamination of cereals and cereal products is widespread in China. DON was detected in 95% of wheat flour from the market in Xiamen in 2013, with a higher detection rate in un-packed, compared to packed, wheat flour [46], and DON was detected in 48% of maize and 98% of wheat from the DON-prevalent regions Anhui and Henan in 2008 [47]. The average DON content was 379.2 μg/kg, maximum 3737 μg/kg. The north west appears to have a lower DON occurrence. The positive rates in wheat and maize flour from Lasa were 27% and 96%, respectively, with a mean of 47 and 24 μg/kg [48]. Wang *et al.* analyzed DON in wheat from 10 regions, including Shandong, Hebei and Jilin, and detected DON in 30% of samples, with a maximum of 850 μg/kg [49]. Although the levels are all below the ML, the exposure risk cannot be ignored, due to frequent contamination.

Using a GC method, DON was detected in 66.46% of wheat samples in Henan, Hubei, Sichuan, Jilin, Guangxi and Guangdong provinces in 2005 [50]. The mean level for DON was 25.88 μg/kg in maize and 50.04 μg/kg in wheat. The dietary exposure of all age groups in both urban and rural populations was below the JECFA PMTDI of 1 μg/kg bw per day. Wang *et al.* [51] investigated DON contamination levels in wheat flour and maize in China and estimated the exposure levels using a random sampling with replacement method and a Monte Carlo method. DON was detected in all of the 292 wheat flour samples and 97% of 347 maize products, with 1.7% and 4.6% of the wheat flour and maize samples, respectively, above the current MLs. It was estimated that amongst children aged 3–13 years old, 24% had exposure exceeding the PMTDI and 16% of children over 14 years old had exposure exceeding the PMTDI.

Taken together, these results suggest that whilst DON contamination is common, the level of contamination in Chinese foods is low, and 95% of people have a safe dietary DON intake level. However, vigilance is required because some samples may contain higher than the ML and children may be at particular exposure risk.

Hidden or "masked" DON refers to metabolites of DON that can be metabolized after ingestion to release DON, effectively increasing the exposure to DON. Masked DON, which is produced by covalent binding with polar compounds in cereals to produce compounds including 3-Ac-DON, 15-Ac-DON and DON-3-glucoside, is not easily detected using conventional methods. Enzymatic reaction in the mammalian gastrointestinal tract transforms the masked DON to free DON, which causes toxicity. A study investigated 650 samples, including maize, maize products, wheat flour, rice and peanuts from 12 provinces in China in 2010 [23]. DON and DON metabolites were analyzed by ultra-performance liquid chromatography tandem mass spectrometry (UPLC-MS/MS). The most contaminated were maize samples with detection rates of 84.7%, 71.6% and 92.6% for DON, 3-Ac-DON and 15-Ac-DON, respectively. Seven out of the 215 maize samples exceeded the ML of 1000 μg/kg in China. Levels of DON, 3-Ac-DON and 15-Ac-DON in wheat and products from 24 provinces in China between 2008 and 2011 were measured by Li *et al.* using UPLC-MS/MS [52]. Nine wheat flour samples exceeded the ML. DON-3-Glucoside was detected in all DON-positive samples. The most contaminated were wheat grain and wheat flour samples in 2008 (range: 4–238 μg/kg; median: 52 μg/kg), whilst the least contaminated year was 2011 (range: 3–53 μg/kg; median: 14 μg/kg).

7.5 T-2 Toxin

T-2 toxin, a toxic metabolite of *F. sporotrichioides* primarily, is one of the most toxic trichothecenes. Immunotoxicity and haemototoxicity are the most commonly observed toxic effects in animal studies. T-2 toxins may contribute to the high prevalence of Kashin–Beck disease, a chronic endemic osteochondropathy of unclear etiology in North East China. It has been associated with numerous outbreaks in farm animals and humans, with symptoms including vomiting, diarrhea, weight loss, immune impairment and increased infection [53].

Maize, barley, wheat, oats, rice, legumes, grain products, including alcoholic products, and feedstuff can be contaminated with T-2 toxin [54]. Food contamination levels of T-2 in China has become increasingly low over recent years. The estimated dietary exposure of T-2 toxin in the Chinese population is generally lower than JECFA PMTDI of 60 ng/kg bw per day [53], although exposure risk is relatively high in specific areas of North East China.

7.6 ZEN

7.6.1 Introduction

ZEN is a toxic metabolite mainly produced *by F. graminearum, F. culmorum, F. semitectum, F. equiseti* and *F. cerealis*. ZEN is widely spread in temperate regions, frequently contaminating barley, wheat, sorghum, millet, rice, soybeans and its products, flour and malts, especially in maize, which is considered to be the most susceptible to ZEN. For optimal growth on maize, the *Fusarium* species generally require humidity in the range of 22–25%, but for production of ZEN, the favored conditions are humidity of 45% and temperature of 24–27 °C for seven days or 12 14 °C for four to six weeks.

In mammals, there are two stereoisomeric metabolites of ZEN, namely α-zearalenol and β-zearalenol. These metabolites are naturally found at much lower levels than ZEN.

7.6.2 Methods for Detection of ZEN

In China, several standard methods for the detection of ZEN have been published; for instance, GB/T 5009.209-2008, GB/T 23504-2009 and GB/T 21982-2008. The first two regulations suggest determining ZEN in cereals such as maize, wheat (LOD is 5 μg/kg), rice and rice products (LOD is 20 μg/kg), soy sauce, vinegar and sauces (LOD is 50 μg/kg) using HPLC with the IAC clean-up method; the third regulation uses LC-MS/MS to determine ZEN concentration in beef, pork, beef liver, milk and egg with the LOD at 0.001 mg/kg.

7.6.3 Toxicity of ZEN

ZEN is an oestrogenic mycotoxin and is implicated in mycotoxicosis in pigs. Exposure to ZEN can cause a series of estrogen-related syndromes in female livestock and poultry, such as cornification of vaginal epithelium, metrauxe, abortion and pseudoestrus [55], which result in significant economic losses for farmers. In addition, pathology of the liver and kidney, altered immune function and induced oxidative stress have been observed in a dose-dependent manner [56].

7.6.4 Occurrence of ZEN in China

During 2007 and 2008, 22.9% (44/192) of wheat samples and 41.7% (85/204) of maize samples were found to be positive for ZEN, with a median level of 8.0 μg/kg in wheat (range from 1.7 to 3425.0 μg/kg) and 48.5 μg/kg in maize (range from 1.6 to 4808.7 μg/kg), respectively. Among these samples, 6 wheat samples and 37 maize samples were found to exceed the China ML of 60 μg/kg [52]. In 2010, 149 of 215 maize samples were determined as ZEN positive and the concentration of ZEN in 23 out of the 149 positive samples exceeded the China ML of 60 μg/kg 4.3-fold [23].

Xiong KH *et al.* [47] analyzed ZEN levels in 37 wheat samples and 36 maize samples in Anhui and Henan provinces. ZEN was detected in 75.3% of the samples, and the concentration of ZEN ranged from 84–388 μg/kg with the mean level of 168 μg/kg being threefold higher than the China ML. This study indicated that ZEN contamination is very severe in these two provinces. Samples in bulk were more likely to be contaminated by ZEN than packaged samples [46]. Pan *et al.* investigated ZEN levels in 252 rice samples collected from seven provinces [57]. ZEN was found in 25% of rice samples with 10% having levels above the China ML. The average level of ZEN was 17.3 μg/kg. The contamination was more severe in some regions than others (Fujian > Jiangxi > Henan > Zhejiang > Jiangsu > Hubei > Hunan), where Fujian province was found to have the highest positive rate at 50%, and Hunan province was reported with the lowest detection rate of 16%. The contamination of ZEN was highly prevalent in feed, feed ingredients and maize by-products in China, with the highest level up to 1816.1 μg/kg, the detection rate 74% and the over-limit rate 15% [58, 59]. Distillers dried grains with solubles (DDGS), soybean residues and pig complete feed samples were also frequently contaminated by ZEN. The mean level of ZEN was up to 882.7 μg/kg in DDGS and 109.1 μg/kg in maize [60].

Using random sampling methods and a Monte Carlo method to determine the exposure levels of ZEN, Wang *et al.* [51] found that ZEN was detected in 53% (156/292) and 88% (304/347) of the wheat flour and maize products; 16% (54/347) of the positive maize samples exceeded the ML of ZEN in food, but no wheat flour samples exceeded the ML. In children aged between 3 and 13 years, 3% exceeded the TDI, their p95 exposure level was 0.25 μg/kg bw per day. For those above 14 years old, 2% exceeded the TDI. The results suggested that the contamination levels of ZEN in wheat flour and maize products were relatively low in China, so the exposure risk is low in the Chinese. Children aged 3–13 years are at higher exposure risk than adults.

7.7 Combined Exposures

It is often the case that some food crops can be contaminated by different varieties of mycotoxins, and there is increasing recognition of the need to take co-exposure into account when considering the potential risk associated with exposure. Co-exposure could lead to additive or multiplicative health risks. To assist in such measurements, there have been recent advances in multi-mycotoxin detection methods.

Li *et al.* [61] developed a UPLC-MS/MS method for detection of wheat DON and masked DON including 3-Ac-DON, 15-A-DON and DON-3-glucoside. The LOD was 0.1 μg/kg for all three. Wang *et al.* [62] developed IAC purification and an HPLC method for simultaneous detection of DON, 3-Ac-DON and 15-Ac-DON in wheat, with an LOD of 100 μg/kg for all three. The method is simple and quick, with good sensitivity and specificity. Zhang *et al.* [63] developed an UPLC-MS/MS method following liquid and SPE extraction for multi-detection of DON, 3-Ac-DON, 15-Ac-DON, NIV and Fusarenon X (4-acetyl-nivalenol).

The contamination of AFB_1, DON, ZEN, FB_1 and T-2 toxin in feed and feed ingredients from Henan, Hebei, Jiangxi in 2002 and another eight provinces in 2013 was investigated by Du *et al.* [64]. Maize, soybean residues, bran and other ingredient samples were all reported to contain mycotoxins. Moreover, 97% of samples were found to be contaminated with more than two types of mycotoxin. ZEN was the most detected at 100%, the highest level was 780.6 μg/kg and the average and median levels were 133.6 μg/kg and 108.6 μg/kg, respectively. Maize was the most and soya bean residue the least contaminated products by ZEN.

Li *et al.* [65] reported that 53%, 35% and 45% of DON, NIV and AFB_1, respectively, were detected in 100 wheat samples from the Shanghai region using TLC and GC methods. The levels were 280.9, 103.4 and 0.9 μg/kg, respectively; 13 of the 100 samples were simultaneously contaminated by all three mycotoxins. The level of DON was correlated with that of NIV, but no correlation was found between AFB_1 and DON or NIV. In another study DON/NIV were detected in 86.7 and 56.7% of 30 wheat flour samples collected in 1998, at levels of 101.3 and 53.3 μg/kg, respectively, with higher levels found in standard flours than in bran-removed flour.

The dominant mycotoxins detected in 447 and 650 wheat and maize samples collected in 2007–2008 and 2010, respectively, were found to be ZEN and DON (23,52). In addition, these samples were also contaminated with other types of mycotoxin such as NIV, Fusarenon X, HT-2, T-2 and AFB_1, AFB_2, AFG_1, AFG_2, to different degrees.

Exposure assessment of DON, NIV and ZEN in China in 2009 from wheat flour and maize consumption showed that, in an average consumer group, there are 2.5% of adults and 10% of children exceeding the TDI level of DON. Dietary exposure of the three mycotoxins was found to be higher in children than in adults, therefore children are at high risk of dietary exposure to DON, ZEN and NIV. Long-term intake of highly DON- or ZEN-contaminated wheat flour and maize products is more likely to cause health problems. If DON derivatives had been considered in this study, the dietary exposure to the combination of DON and its derivatives would exceed the TDI. On the basis of the international standards, it is necessary to investigate DON, 3-Ac-DON and 15-Ac-DON instead of assessing DON only in the food regulations.

7.8 Regulations, Control and Surveillance

7.8.1 Aflatoxins

Aflatoxins are the most regulated mycotoxins owing to their toxicities and health risks, particularly carcinogenicity. Over 100 countries have defined MLs for aflatoxins. For cereals and nuts, most MLs range between 10 and 20 μg/kg, although the EU sets the lowest limit, at 4 μg/kg. For AFM_1, most countries set the ML at either 0.05 (EU) or 0.5 μg/kg (others and CAC).

Mycotoxin food standards were set in China in 2003 (GB 9676-2003), and were renewed in 2005 (GB2761-2005), including AFB_1, AFM_1, DON and patulin. The recent GB2761-2011 has revised AFB_1, AFM_1, DON and patulin MLs, adding OTA and ZEN MLs, and baby food (<0.5 μg/kg) and special food groups. In the 2011 GB, maize, nuts and peanut oil MLs for aflatoxin B_1 are kept unchanged at 20 μg/kg; total aflatoxins have not been regulated in China.

Aflatoxin reduction can be at individual, public and government level. Individual intervention measures include using clean food, adopting a more diverse diet that does not rely on susceptible crops, and use of chemopreventive agents for enhanced detoxification (e.g., chlorophyllin, green tea polyphenols) or excretion (e.g., clay). However, a more sustainable reduction of aflatoxin exposure will be achieved by improved agriculture and storage methods to reduce contamination of the food crops.

7.8.2 Fumonisins

Regulations on fumonisins are less well developed. The European Commission (EC) regulation for $FB_1 + FB_2$ in unprocessed maize for human consumption is 4 mg/kg, and in maize for direct human consumption is 1 mg/kg (EC No 1126/2007). Other countries such as Switzerland and the US have also set MLs for maize fumonisins at 1 and 2 mg/kg, respectively. The Chinese government has not set fumonisin MLs as yet.

7.8.3 DON

The JECFA has set the PMTDI for DON and DON metabolites at 1 μg/kg bw per day [56]. China's food safety risk monitoring plan clearly requires detecting DON, 3-Ac-DON and 15-Ac-DON in wheat flour, oats (including oatmeal), and baby complementary food. Moreover, according to the benchmark dose limit (0.21 mg/kg/d) for pigs, the JECFA announced an acute reference dose (8 μg/kg) for DON and acetyl-DON. The EU is considering changing the current limits for DON in grains to the combination of DON and hidden DON. Therefore, more research is focused on detecting DON and its derivatives, and their contamination levels in food.

7.8.4 T-2 Toxin

Currently there is no ML for T-2 toxin in food in China. It is recommended that a standardized sampling and detection approach should be set in order to monitor T-2 levels in different regions across China.

For public health protection, for economics and trading, an ML for T-2 toxin is urgently required and this should be set based on appropriate risk assessment of the occurrence and exposure of T-2, and the toxicity it has in humans and animals.

7.8.5 ZEN

ZEN was firstly evaluated by the JECFA in 1999, and then in its 26th, 27th and 32nd conferences, the two metabolites of ZEN, namely zearalenol (ZEL, include two isomers α-zearalenol and β-zearalenol) and zearalanol (ZAL, including two isomers; α-zearalanol and β-zearalanol) in mammals were considered. At the 32nd conference the acceptable daily intake (ADI) of ZAL was set at 0–0.5 μg/kg when used as a veterinary drug.

For the first time, in 2011, the China National Food Safety Standard GB2761-2011 Maximum levels of mycotoxins in foods set the ML of ZEN in crops and food at 60 μg/kg. Another regulation, GB13078.2-2006 standard for Feeds-Tolerable levels of ochratoxin A and zearalenone in feeds, indicated that the level of ZEN in feed cannot be over 500 μg/kg. However, the MLs of α-zearalenol, β-zearalenol, zearalanol and β-zearalanol in food and feed have not been set.

7.9 Challenges

In China the immediate challenges are the development and, in particular, the subsequent enforcement of national standard limits. Although a food safety risk assessment team and a nationwide food surveillance network have been developed, the lack of scientific evidence on toxicity and exposure risk, and the lack of representative occurrence data from farm to fork hinders the food safety process. Further, problems with effective communication on food safety issues in China exacerbate the situation. Some of the challenges are discussed here.

Except for aflatoxins, toxic effects and human health risks of most mycotoxins are poorly characterized. This increases the uncertainty in risk assessment and hinders the standardization of regulations. A priority is to obtain solid scientific evidence on toxicity and the human health risks of mycotoxins to allow for a comprehensive and appropriate risk assessment. It is increasingly important to understand the problem of mycotoxin exposures in combination, which is being reported more and more frequently in recent years, largely owing to the advances in detection methodology. Co-exposure to multiple mycotoxins is in fact a “norm” of real life. The risk assessment of co-exposure to mycotoxins is a huge challenge we are facing in the coming years.

On the occurrence side, climate change is causing shifts in the patterns of mycotoxin contamination. Mathematical modelling shows the potential increase in aflatoxin occurrence in the future, and this prompts the need for a stronger warning system, such as the Rapid Alert System for Food and Feed (RASFF) in the EU (http://ec.europa.eu/food/safety/rasff/index_en.htm). Increasingly, research has revealed that mycotoxins can co-exist in tens and even hundreds of types; there are also masked mycotoxins (3- and 15-acetylated DON and DON glucoside, for example) and new emerging mycotoxins (enniatins and beauvericin, for example) in our food that potentially exacerbate or alter the associated risk to our health. Strengthened toxin surveillance, advanced detection tools and standardized analytical methods are therefore urgently required in order to understand the magnitude of mycotoxin exposure risk.

Much human health information to date is from ecological studies. Properly designed epidemiological studies providing strong causal relationships between exposure and disease are required. Large-scale public health surveillance of food-borne disease can generate useful information to define the burden of mycotoxin exposure.

There is often repetition and variation in the MLs and the detection method between the national, departmental and disciplinary levels. Integration and standardization of mycotoxin MLs is vital to ensure food safety in China.

Rapid globalization has an impact on many aspects of our lives, including food safety. Because of the important impact on economics and the export/import of food, the harmonization of MLs for the important mycotoxins is a priority issue in global food safety and security, and it requires strong international cooperation to build an effective and sustainable food safety system with international harmonization of regulatory and monitoring systems. In the case of fumonisin, if an ML of 0.5 mg/kg were adopted worldwide, total losses in export maize owing to fumonisins could exceed 300 million USD annually, whilst this loss would only be 100 million USD if less stringent MLs, like the US 2 mg/kg, were adopted. If the aflatoxin ML in peanuts was reduced from 20 to 4 μg/kg the export loss would increase fivefold to 450 million USD. It is estimated that countries like China and Argentina would experience the greatest loss from tighter mycotoxin standards [66]. It has been documented that the associated reduced health risk due to decrease in aflatoxin MLs would not be significant, and it is therefore reasonable to consider a balanced approach to MLs that reduces the impact on economic development, whilst maintaining safety.

The recent "one health" paradigm proposed by the WHO introduces a new risk analysis approach, which holistically focuses on health safety from farm to fork, through good food production practices in all sectors, to public education on a healthy diet. Likewise, in China the food safety management system across the whole food chain must act together in order to ensure mycotoxin reduction in food and effective management.

References

1 Pitt JI, Wild CP, Baan RA, Gelderblom WCA, Miller JD, Riley RT, Wu F (2012) *Improving Public Health through Mycotoxin Control*. IARC Scientific Publication, No 158 pp. 5.

2 Routledge MN and Gong YY (2011) Developing biomarkers of human exposure to mycotoxins. (Ed) S De Saeger, In *Determining Mycotoxins and Mycotoxigenic Fungi in Food and Feed*, pp.225–244, Woodhead Publishing, Cambridge, UK.

3 Azziz-Baumgartner E, Lindblade K, Gieseker K, Schurz Rogers H, Kieszak S, Njapau H, Schleicher R, McCoy LF, Misore A, DeCock K, Rubin C, Slutsker L and the Aflatoxin Investigation Group (2005) Case-control study of an acute aflatoxicosis outbreak, Kenya, 2004. *Environmental Health Perspectives* 113, 1779–1783.

4 Wang JS, Qian GS, Zarba A, He X, Zhu YR, Zhang BC, Jacobson L, Gange SJ, Muñoz A, Kensler TW, Groopman JD (1996) Temporal patterns of aflatoxin-albumin adducts in hepatitis B surface antigen-positive and antigen-negative residents of Daxin, Qidong County, People's Republic of China. *Cancer Epidemiol Biomarkers Prev.* 5, 253–261.

5 Guo HW (1991) The study of the relationship between diet and primary liver cancer. *Chinese Journal of Preventive Medicine* 25, 342–344.

6 Yu SZ (1992) The aflatoxins and liver cancer in Guangxi, China. *Chinese Journal of Preventive Medicine* 26, 162–164.

7 Tang LL, Tang M, Xu L, Luo HT, Huang TR, Yu JH, Zhang LS, Gao WM, Cox SB and Wang JS (2008) Modulation of aflatoxin biomarkers in human blood and urine by green tea polyphenols intervention. *Carcinogenesis* 29, 411–417.

8 Wang LY, Hatch M, Chen CJ, Levin B, You SL, Lu SN, Wu MH, Wu WP, Wang LW, Wang Q, Huang GT, Yang PM, Lee HS, Santella RM (1996) Aflatoxin exposure and risk of hepatocellular carcinoma in Taiwan. *International Journal of Cancer* 67, 620–625.

9 Ross RK, Yuan JM, Yu MC, Wogan GN, Qian GS, Tu JT, Groopman JD, Gao YT and Henderson BE (1992) Urinary aflatoxin biomarkers and risk of hepatocellular carcinoma. *Lancet* 339, 943–946.

10 Wu HC, Wang Q, Yang HI, Ahsan H, Tsai WY, Wang LY, Chen SY, Chen CJ and Santella RM (2009) Aflatoxin B1 exposure, hepatits B virus infection, and hepatocellular carcinoma in Taiwan. *Cancer Epidemiology Biomarkers and Prevention* 18, 846–853.

11 Tao P, Zhi-Ming L, Tang-Wei L, Le-Qun L, Min-Hao P, Xue Q, Lu-Nam Y, Ren-Xiang L, Zong-Liang W, Lian-Wen W, Han-Ming S, Choon-Nam O and Santella RM (2005) Associated factors in modulating aflatoxin B1-albumin adduct level in three Chinese populations. *Digestive Diseases and Sciences* 50, 525–532.

12 Lu PX, Wang JB, Zhang QN Wu Y, Sun Y, Chen TY (2010) Longitudinal study of aflatoxin exposure in the development of primary liver cancer in patients with chronic hepatitis. *Chinese Journal of Preventive Medicine* 90, 1665–1669.

13 Sun ZT, Chen TY, Thorgeirsson SS, Zhan QM, Chen JG, Park JH, Lu PX, Hsia CC, Wang NJ, Xu LB, Lu LL, Huang F, Zhu YR, Lu JH, Ni ZP, Zhang QA, Wu YY, Liu GT, Wu ZY, Qu CF, Gail MH (2013) Dramatic reduction of liver cancer incidence in young adults: 28-year follow-up of etiological interventions in an endemic area of China. *Carcinogenesis* 34,1800–1805.

14 Wang J, Liu XM, Zhang ZQ (2009) Exposure assessment of liver cancer attributed to dietary aflatoxins exposure in Chinese residents. *Chinese Journal of Preventive Medicine* 43, 478–481.

15 Gong YY, Cardwell K, Hounsa A, Egal S, Turner PC, Hall AJ, and Wild CP (2002) Dietary aflatoxin exposure and impaired growth in young children from Benin and Togo: cross sectional study. *British Medical Journal* 325, 20–22.

16 Gong YY, Hounsa A, Egal S, Turner PC, Sutcliffe AE, Hall AJ, Cardwell K and Wild CP (2004) Postweaning exposure to aflatoxin results in impaired child growth: a longitudinal study in Benin, West Africa. *Environmental Health Perspectives* 112, 1334–1338.

17 Turner PC, Moore SE, Hall AJ, Prentice AM and Wild CP (2003) Modification of immune function through exposure to dietary aflatoxin in Gambian children. *Environmental Health Perspectives* 111, 217–220.

18 Castelino JM, Routledge MN, Wilson S, Dunne DW, Mwatha JK, Gachuhi K, Wild CP, Gong YY (2015) Aflatoxin exposure is inversely associated with IGF1 and IGFBP3 levels in vitro and in Kenyan schoolchildren. *Molecular Nutrition and Food Research* 59, 574–581.

19 Jiang Y, Jolly PE, Ellis WO, Wang J-S, Phillips TD and Williams JH (2005) Aflatoxin B1 albumin adduct levels and cellular immune status in Ghanaians. *International Immunology* 17, 807–814.

20 Li FQ, Yoshizawa T, Kawamura O, Luo XY, Li YW (2001) Aflatoxins and fumonisins in maize from the high-incedence area for human hepatocellular carcinoma in Guangxi, China. *Journal of Agricultural and Food Chemistry* 49, 4122–4126.

21 Li R, Wang X, Zhou T, Yang D, Wang Q and Zhou Y (2014) Occurrence of four mycotoxins in cereal and oil products in Yangtze Delta region of China and their food safety risks. *Food Control* 35, 117–122.

22 Gao X, Yin S, Zhang H, Han C, Zhao X, Ji R (2011) Aflatoxin contamination of corn samples collected from six regions of China. *Wei Sheng Yan Jiu* 40, 46–49.

23 Ma JJ, Shao B, Lin XH, Yu HX, Li FQ (2011) Study on the natural occurrence of multi-mycotoxin in cereal and cereal-based product samples collected from parts of China in 2010. *China Journal of Food Hygiene* 23, 481–488.

24 Wang J and Liu XM (2007) Contamination of aflatoxins in different kinds of foods in China. *Biomedical Environmental Science* 20, 483–487.

25 Ding XX, Li PW, Bai YZ, Zhou HY (2012) Aflatoxin B1 in post-harvest peanuts and dietary risk in China. *Food Control* 23, 143–148.

26 Selvaraj JN, Wang Y, Zhou L, Zhao Y, Xing F, Dai X and Liu Y (2015) Recent mycotoxin survey data and advanced mycotoxin detection techniques reported from China: a review. *Food Additives and Contaminants: Part A* 32, 440–452.

27 Li FQ, Li YW, Wang YR, Luo XY (2009) Natural occurrence of aflatoxins in chinese peanut butter and sesame paste. *Journal of Agricultural and Food Chemistry* 57, 3519–3524.

28 Bolger M, Coker RD, DiNovi M, Gaylor D, Gelderblom W, Olsen M, Paster N, Riley RT, Shephard G, Speijers GJA (2001). Fumonisins. In *Safety Evaluation of Certain Mycotoxins in Food: Prepared by the 56th meeting of the Joint FAO/WHO Expert Committee on Food Additives (JECFA).* WHO Food Additives Series, Vol. 47 (pp. 103e279). WHO, FAO Food and Nutrition Paper 74, Geneva, Switzerland.

29 Shephard GS, Marasas WF, Yazdanpanah H, Rahimian H, Safavi N, Zarghi A, Shafaati A, Rasekh HR (2002). Fumonisin B (1) in maize harvested in Iran during 1999. *Food Additives and Contaminants* 19, 676–679.

30 Wild CP and Gong YY (2010) Mycotoxins and human disease: a largely ignored global health issue. *Carcinogenesis* 31, 71–82.

31 Xu L, Cai Q, Tang L, Wang S, Hu X, Su J, Sun G, Wang JS (2010) Evaluation of fumonisin biomarkers in a cross-sectional study with two high-risk populations in China. *Food Additives and Contaminants, Part A Chemistry, Analysis, Control, Exposure and Risk Assessment* 27, 1161-9.

32 Sun G, Wang S, Hu X, Su J, Huang T, Yu J, Tang L, Gao W, Wang JS (2007) Fumonisin B1 contamination of home-grown corn in high-risk areas for esophageal and liver cancer in China. *Food Additives and Contaminants* 24, 181–185.

33 Wang H, Wei H, Ma J, Luo X (2000) The fumonisin B1 content in corn from North China, a high-risk area of esophageal cancer. *Journal of Environmental Pathology, Toxicology and Oncology* 19,139–141.

34 Ueno Y, Iijima K, Wang SD, Sugiura Y, Sekijima M, Tanaka T, Chen C, Yu SZ (1997). Fumonisins as a possible contributory risk factor for primary liver cancer: a 3-year study of corn harvested in Haimen, China, by HPLC and ELISA. *Food Chemistry and Toxicology* 35, 1143–1150.

35 Abnet CC, Borkowf CB, Qiao YL, Albert PS, Wang E, Merrill AH Jr, Mark SD, Dong ZW, Taylor PR, Dawsey SM (2001) Sphingolipids as biomarkers of fumonisin exposure and risk of esophageal squamous cell carcinoma in china. *Cancer Causes and Control* 12, 821–828.

36 Wei T, Zhu W, Pang M, Liu Y, Dong J (2013) Natural occurrence of fumonisins B1 and B2 in corn in four provinces of China. *Food Additives and Contaminants, Part B Surveillence* 6, 270–274.

37 Feng YZ, Lu XH, Tao B, Pang MH, Liu YC, Dong JG (2011) Natural occurrence of fumonisins b1 and b2 in corn from three main production provinces in China. *Journal of Food Protection* 74, 1374–1378.

38 Fu M, Li R, Guo C, Pang M, Liu Y, Dong J (2015) Natural incidence of Fusarium species and fumonisins B1 and B2 associated with maize kernels from nine provinces in China in 2012. *Food Additives and Contaminants, Part A Chemistry, Analysis, Control, Exposure and Risk Assessment* 32, 503–511.

39 Li F, Jiang D, Zheng F, Chen J, Li W (2015) Fumonisins B_1 B_2 and B_3 in corn products, wheat flour and corn oil marketed in Shandong province of China. *Food Additives and Contaminants, Part B Surveillence* 8, 1–6.

40 Liu YP, Yang LX, Yang NJ, Dong B, Cao LL, Wang K, Yang LX (2012) Occurrence of fumonisins and aflatoxins in cereals from markets of Hebei Province of China. *Food Additives and Contaminants, Part B Surveillence* 5, 208–211.

41 Turner PC Rothwell JA, White KLM, Gong YY, Cade JE and Wild CP (2008) Urinary deoxynivalenol is correlated with cereal intake in individuals form the United Kingdom. *Environmental Health Perspectives* 116, 21–25.

42 Turner PC, Ji BT, Shu XO, Zheng W, Chow WH, Go YT and Hardie LJ (2011) A biomarker survey of urinary deoxynivalenol in China: The Shanghai Women's health Study. *Food Additives and Contaminants Part A: Chemistry, Analysis, Control, Exposure and Risk Assessment* 28, 1220–1223.

43 JECFA (2011) *Evaluation of Certain Food Additives and Contaminants: Seventy-Third Report of the Joint FAO/WHO Expert Committee on Food Additives*. Geneva, World Health Organization, Joint FAO/WHO Expert Committee on Food Additives (WHO Technical Report Series No. 960).

44 Luo XY (1994) Food poisoning caused by fusarium toxins. *Proceedings of the Second Asian Conference on Food Safety*, pp. 129–136

45 Li FQ, Li YW, Luo XY, Yoshizawa T (2002) Fusarium toxins in wheat from an area in Henan Province, PR China, with a previous human red mold intoxication episode. *Food Additives and Contaminants* 19(2), 163–167.

46 Bai YY, Chen LH, Jia YZ (2014) Analysis of the monitoring of three categories of mycotoxins in wheat flour and cornmeal from Xiamen markets in 2013. *Chinese Journal of Health Laboratory Technology* 14, 2068–2069.

47 Xiong KH (2010) Survey on the contamination of deoxynivalenol and zearalenone in cereals and screening of microorganism for mycotoxin degradation. *Journal of Nanchang University*, 12, 1–79.

48 Si LL (2014) Analysis of the monitoring results of deoxynivalenol and zearalenone in wheat flour and cornmeal from Lasa markets. *Xizang Technology* 12, 25–28.

49 Wang S, Zhang Y, Cui Y, Chen WS (2014) The investigation of DON contents in wheat flour samples and analysis of DON dietary exposure risk. *Food Research and Development* 22, 94–96.

50 Wang XY, Yu YQ, Yu Q (2007) Survey of the natural occurrence of deoxynivalenol(DON) and the assessment of dietary exposure of Chinese populations in 2005. *Journal of Changzhi Medical College* 21(2),101–103.

51 Wang W, Zhu JH, Shao B, Li FQ (2015) Assessment of dietary exposure to both deoxynivalenol and zearalenone from cereal-based products in Chinese populations. *Chinese Journal of Preventive Medicine* 49(3):223–227.

52 Li FQ, Yu CC, Shao B, Yu HX (2011) Natural occurrence of masked deoxynivalenol and multi-mycotoxins in cereals from China harvested in 2007 and 2008. *Chinese Journal of Preventive Medicine* 45(1):57–63.

53 JECFA (2001) *Safety Evaluation of Certain Food Additives and Contaminants.* WHO Food Additives Series 46, Geneva.

54 Li M (2006) *Investigation on the natural occurrence of T-2 toxin in wheat and corn and risk assessment of the dietary intake in six provinces in China.* Jilin University, 1–51.

55 Jiang SZ (2010) An initial study on the toxicity of zearalenone of post-weaning gilts and the effects of detoxification of modified montmorillonite. *Journal of Shandong Agricultural University* 5, 1–171.

56 Ma YJ, Xu LN, Li YG, Fan XL, Liang ZS, Deng XB (2009) Effects of zearalenone on apoptosis of splenic lymphocytes in mice. *Actaecologae Animals Domastici* 30(1),52–56.

57 Pan HY (2012) Survey on the contamination of zearalenone in rice and toxicological experiment research. *Journal of Wuhan Polytechnic University* 5, 1–79.

58 Zhang C, Liu YL (2010) Investigation of mycotoxins contamination in feed and feed ingredient in 2009. *China Poultry* 32(6), 6–69.

59 Yang XF, Yu B, Chen DW, Bai F, Feng Y (2007) Report on the investigation of mycotoxins in feed ingredients from Sichuan in 2006. *Feed Industry* 28(13), 61–64.

60 Lei YP, Ma QG, Xie SY, Zhao LH, Fan Y, Li XY, Wang L, Qiao SY, Yun P, Ji C (2012) Investigation of natural occurance of zearalenone in feeds and feedstuffs of pig farms in the Beijing area. *Acta Zoonutrimenta Sinica* 24(5), 905–910.

61 Li FQ, Wang W, Ma JJ, Yu CC, Lin XH, Yan WX (2012) Natural occurrence of masked deoxynivalenol in Chinese wheat and wheat-based products during 2008–2011. *World Mycotoxin Journal* 5, 221–230.

62 Wang P, Xu GC, Yin LM, Li R, Xie G (2015) Simultaneous determination of deoxynivalenol and its derivaties in wheat by immune affinity column and high performance liquid chromatography. *Science and Technology of Cereals, Oils and Foods* 23(1), 63–66.

63 Zhang JF, Sun YF, Li JP, An H, Wang XJ (2014) Ultra high performance liquid chromatography-mass spectrometry for detection of type B trichothecene in food. *Chinese Journal of Health Laboratory Technology* 13, 1856–1858.

64 Du N (2014) Report on the investigation of mycotoxins contamination in feed and feed ingredients in some areas of China in 2013. *Market Research* 3, 48–52.

65 Li X, Wei GH, Xu J (1997) Studies on mycotoxins contamination on wheat in Shanghai. *Shanghai Preventive Medicine* 9, 413–415

66 Wu F (2004) Mycotoxin risk assessment for the purpose of setting international regulatory standards. *Environmental Science and Technology* 38, 4049–4055.

8

Viruses

Jennifer L. Cannon, Lingling Liu and Wei Kang

Center for Food Safety, Department of Food Science and Technology, University of Georgia, USA

8.1 Introduction

The staggering boom of China's economy continues to capture news headlines. Standards of living continue to improve and heavy investments in public health infrastructure have been made over the last decade. Accordingly, Chinese people are pursuing healthier lifestyles and are becoming more aware of food safety issues. As China's epidemiologic surveillance tools and networks are implemented and enhanced, food-borne illnesses have emerged as major concerns to public health. As such, food-borne illnesses are among the largest food safety issues in China today [1].

As in many countries, an important group of pathogens causing food-borne illnesses are under-represented in food-borne disease surveillance reports in China. Although historically under-reported, food-borne viruses are recently being recognized as important food-borne pathogens in the US, Europe, Australia, and Japan and are likely to emerge as prominent food-borne pathogens globally.

Food-borne viruses include at least 10 virus families with symptoms ranging from mild diarrhea to severe encephalitis [2]. They are typically enteric viruses transmitted primarily by the fecal-oral route. Transmission can occur directly via contact with the contaminated hands of infected individuals or aerosolized vomit. Indirect transmission also occurs as a result of contact with contaminated environmental surfaces or consumption of foods or water impacted by fecal material. Foods typically implicated in outbreaks of food-borne illness due to viruses include raw shellfish, uncooked produce, and prepared or ready-to-eat foods that undergo a high degree of handling prior to consumption. This is because most food-borne viruses are host-specific; strains that infect humans do not infect animals and vice versa. However, there is a subset of food-borne viruses with strains that infect both animal and human hosts. Unlike bacterial pathogens, viruses cannot replicate outside of cells within a susceptible host. As such, food-borne viruses have evolved to become uniquely persistent in harsh environmental conditions and are moderately resistant to several disinfectants used to combat bacterial pathogens.

This chapter will provide a unique examination of the status of food-borne viruses in China. It will first provide an introduction to and characteristics of specific groups of

Food Safety in China: Science, Technology, Management and Regulation, First Edition.
Edited by Joseph J. Jen and Junshi Chen.

food-borne viruses known to cause illnesses and outbreaks in China and globally (as outlined in Table 8.1). In the next section, the current status of the problem of food-borne viruses in China will be discussed. Details about epidemiologic surveillance programs in place or under development will be described. Outbreak reports involving food handlers, fresh produce, and shellfish will be highlighted, and recently published guidance documents and reviews for food-borne virus prevention and control will be discussed. Much of the focus in this section will be on a specific group of viruses, known as human noroviruses, as this group is increasingly being recognized as the most common agent of epidemic gastroenteritis, globally. The last section will discuss what is needed to better understand the issue of food-borne viruses in China and future perspectives.

8.2 Overview of Specific Food-borne Viruses Important in China and Globally

The majority of food-borne viruses cause symptoms of acute gastroenteritis. These viruses include; caliciviruses (noroviruses and sapoviruses), rotaviruses, astroviruses, and aichiviruses. Among these viruses, noroviruses cause the majority of outbreaks and illnesses of food-borne viral gastroenteritis. Rotaviruses are the leading cause of severe childhood diarrhea globally, but are seldom reported to be associated with consumption of contaminated food. Sapoviruses and astroviruses are also commonly associated with mild gastroenteritis in children, but food-borne outbreaks among adults have been reported [3–5]. Aichiviruses have emerged recently as food-borne pathogens, primarily associated with consumption of raw shellfish [6,7]; however, since they are commonly associated with co-infection with other viruses known to cause gastroenteritis, their importance as food-borne pathogens is still unknown.

Two other viruses that will be discussed in detail cause acute, normally self-limiting hepatitis. Hepatitis A virus (HAV) and hepatitis E virus (HEV) are endemic in many regions of the world where water quality is poor, and limited access to good sanitation is common. Most often, children in these regions develop asymptomatic infection by HAV and are protected from subsequent infections. The majority of HAV illnesses occur in adult populations when unexposed persons travel to endemic regions or HAV-contaminated food is exported from countries where the virus is endemic. HEV has been the cause of several very large outbreaks of water-borne illnesses in developing countries [8,9]. It has also been linked to the consumption of wild game meat and uncooked sausages in developed countries, demonstrating its capability of causing zoonotic infections [10].

Other viruses transmitted by the fecal-oral route and found in feces of humans and animals include the adenoviruses, enteroviruses, parvoviruses, toroviruses, picobirnaviruses, coronaviruses, and the tick-borne encephalitis virus. Enteric strains of adenovirus (types 40 and 41) and enteroviruses are commonly detected in human fecal material and have therefore been used as indicators for fecal pollution in environmental water and on foods [11]. Parvoviruses, including human bocoviruses, toroviruses, and picobirnaviruses are viruses that do not have a clear association as being the causative agents of gastroenteritis, but have been detected in the feces of humans experiencing gastroenteritis symptoms and in human sewage. Tick-borne encephalitis (TBE)

Table 8.1 Characteristics of food-borne viruses.

Virus	Norovirus	Sapovirus	Rotavirus	Astrovirus	Aichivirus	HAV	HEV
Baltimore classification	Group IV	Group IV	Group III	Group IV	Group IV	Group IV	Group IV
Genome composition	(+) ss RNA	(+) ss RNA	(+) ds RNA	(+) ss RNA	(+) ss RNA	(+) ss RNA	(+) ss RNA
Family	*Caliciviridae*	*Caliciviridae*	*Reoviridae*	*Astroviridae*	*Picornaviridae*	*Picornaviridae*	*Hepeviridae*
Genus	Norovirus	Sapovirus	Rotavirus	Mammoastrovirus	Kobuvirus	Hepatovirus	Orthohepevirus
Envelope	No	No	No	No	No	No	No
Virion diameter (nm)	28–35	30–38	60–80	28–30	20–40	27–32	27–34
Size (kb)	7.4–7.7	7.1–7.7	16–27	6.8-7.8	8.2	7.5	7.5
Symptoms	Epidemic gastroenteritis	Gastroenteritis	Gastroenteritis	Gastroenteritis	Gastroenteritis	Inflammation of liver, hepatitis	Inflammation of liver, hepatitis
Vaccine availability	No	No	Yes	No	No	Yes	Yes, but only available in China
Transmission route	Person-to-person, food-borne, water-borne	Person-to-person, food-borne, water-borne	Person-to-person, food-borne, water-borne	Person-to-person, food-borne, water-borne	Person-to-person, food-borne, water-borne	Person-to-person, food-borne, water-borne	Person-to-person, food-borne, water-borne, zoonotic

viruses cause encephalitis and are transmitted most commonly by ticks of the *Ixodes* species. Food-borne disease is far less common, but has been associated with consumption of unpasteurized dairy products from infected cattle and goats [12]. Two coronaviruses, SARS (severe acute respiratory syndrome) and MERS (Middle East respiratory syndrome) coronaviruses (CoVs), have recently been the cause of severe atypical pneumonia, causing large outbreaks in 2002 and 2012, respectively. Zoonotic transmission of SARS-CoV has been linked to palm civets and raccoon dogs sold at exotic markets in China [13]. While there has not been direct evidence for zoonotic transmission of MERS-CoV, dromedary camels have been implicated as causative agents [14]. The majority of these viruses are considered minor or potential food-borne pathogens. They have either been the cause of a small number of past outbreaks or no food-borne disease has been reported to be associated with them, but there is a possibility that more virulent or transmissible strains of these viruses might emerge. Readers are referred to a published review for more information about their potential role as food-borne pathogens [15].

8.2.1 Norovirus

Noroviruses (NoVs), previously called Norwalk-like viruses, are members of the Norovirus genus, belonging to the *Caliciviridae* family. Human noroviruses (HuNoVs) are the leading cause of food-borne illnesses in US, responsible for 58% of food-borne gastroenteritis illnesses and 95% of nonbacterial gastroenteritis illnesses each year [16]. The economic impact from food-borne and water-borne outbreaks of norovirus illnesses is estimated to be $5.8 billion annually in the US [17]. Estimates from the Food-borne Viruses in Europe Network recently reported that 21% of all norovirus outbreaks had a food-borne transmission route [18]. Although food-borne disease is common for HuNoVs, the person-to-person route is its primary means of transmission. Of the 1206 HuNoV gastroenteritis outbreaks reported in New Zealand in 2002–2009, 65% occurred in healthcare settings and 17% were associated with shellfish consumption or catered events [19]. The majority of food-borne outbreaks of HuNoVs in China reported to date involve either shellfish or food handlers.

HuNoVs are transmitted primarily person-to-person by direct contact, aerosolized vomit or contact with contaminated surfaces. They are also commonly associated with food- and water-borne illnesses. In the US from 2001–2008, 886 outbreaks of food-borne HuNoV illnesses were reported with a known food contamination route; 82% of these outbreaks involved food handler contact and 13% indicated contamination of the raw product [20]. Foods most commonly implicated are those that are contaminated at the point of food service, including leafy green salads, deli sandwiches, fruits and vegetables that are consumed raw, and other ready-to-eat foods. Both ill and asymptomatic food handlers have contributed to food contamination at the point of food service. Shellfish, which become contaminated by fecally polluted production waters are also a major source of food-borne HuNoV illnesses. While the number or cases of HuNoV illness due to food contamination prior to the point of food service are likely underestimated, there have been several documented outbreaks involving fresh and frozen berries, and lettuce, where contamination of the foods during production, harvesting, or processing has been highly suspected [21–24]. Zoonotic transmission of noroviruses has not been reported to date. Human infection by animal strains of noroviruses has been documented serologically, where animal norovirus-specific antibodies are generated in humans [25,26]. Considering this and the recombination potential for both human and animal strains, zoonotic transmission is possible, but no illnesses by animal strains have yet been documented in humans.

8.2.2 Sapovirus

Sapoviruses (SaVs) are also members of the *Caliciviridae* family. SaVs are commonly underappreciated, but are responsible for a considerable proportion of viral gastroenteritis outbreaks. While historically associated with pediatric diarrhea, infections among adults have been less frequently reported. Recently, SaV gastroenteritis among adults and elderly persons has been increasingly reported globally [27]. Among 21 sapovirus outbreaks between 2002 and 2009 in Oregon and Minnesota (USA), 66% occurred in long-term care facilities and 10% in grade schools, while the remaining 24% were individual occurrences on a cruise ship, a prison, a psychiatric hospital, a bed and breakfast, and a restaurant [28]. According to a recent review paper [27], among more than 100 papers published on SaV infection, more than 30 strains were detected from patients with sporadic gastroenteritis. Positivity rates in these studies ranged from 2.2% to 12.7%, which usually ranked them the second to fourth most common cause of sporadic viral gastroenteritis [27]. SaV outbreaks are less common, with reports of 1.3% to 8.0% of samples testing postitive for SaV, but SaV positivity rates as high as 5.9 to 22.6% have been reported from samples testing negative for HuNoV and enteric bacteria [27]. Similar ranges for SaV detection have been reported among adults and children in China [29,30].

The most common route of transmission for human SaVs is person-to-person, although several food-borne outbreaks have been reported. In 1997, in the United States, one of the first food-related outbreaks of SaV gastroenteritis was reported among adults at a school [31]. A very large SaV outbreak associated with a food handler preparing boxed lunches at a wedding was described where 109 wedding guest became ill [3]. Similarly, boxed lunches contaminated by food handlers in Japan were responsible for the largest outbreak of SaV reported to date, where 655 persons (17% of those served) became ill [4]. Shellfish have caused numerous outbreaks of SaV gastroenteritis in Japan, as reported after consumption of oysters [32] and clams [6]. There are no reports of zoonotic transmission of sapoviruses to date. However, like HuNoVs, there is potential for recombination among human and animal strains and closely related GVIII sapovirus strains have been detected in both humans and swine [33].

8.2.3 Rotavirus

Rotaviruses are globally the most common cause of diarrhea among children under two years of age. Adults are also susceptible to rotavirus infection, although the resulting illness is rarely severe. In the era before the licensing of two live, oral, second-generation rotavirus vaccines in 2006, rotaviruses were responsible for an estimated 2.4 million hospitalizations and 500 000 child deaths each year, with most deaths occurring in developing countries [34]. The pentivalent RV5 RotaTeq® (Merck and Company, Inc.) and monovalent RV1 Rotarix® (GlaxoSmithKline) vaccines have since been recommended by WHO for all regions of the world since 2009 with licensing in more than 100 countries [35]. Clear reductions in the number of severe illnesses and deaths among rotavirus-infected children have since been reported in middle- and high- income countries, but the impact has not been as high in low-income countries for reasons not entirely known [35].

Rotavirus infections are primarily transmitted through the fecal-oral route and no convincing evidence has suggested aerosolized droplet transmission. Person-to-person transmission and fomite contact (an indirect form of person-to-person transmission) are the most common routes of infection, particularly among child- and elder-care facilities. Rotavirus contamination of foods prepared by persons caring for infants is likely to be an important source of infection among children [36]. Prepared meals contaminated by food handlers have been the cause of several outbreaks of rotavirus gastroenteritis in the United States and Japan [37,38]. Rotavirus outbreaks caused by contamination of foods prior to the point of food service have not been reported, but are possible, as evidenced by rotavirus detection on market lettuce in Costa Rica [39] and on strawberries, green onions and work surfaces in North America [40,41]. Water-borne outbreaks of rotavirus have been reported in several Western countries [42] and China [43], where nearly 1 million persons were effected by a large water-borne outbreak. Likewise, sewage-impacted water was also responsible for rotavirus contamination of shellfish detected recently in China [44]. Zoonotic transmission of rotaviruses has been documented, particularly when domestic animals are reared in close proximity to humans. Reassortment strains containing both human and animal rotavirus genes have either been confirmed or highly suspected to have caused human illnesses in Latin America, Asia, Europe, and Africa [45]. Due to the segmented nature of the genomes of these viruses, their zoonotic potential through reassortment is high.

8.2.4 Astrovirus

Human astroviruse (HAstV) outbreaks of gastroenteritis are not as common as those caused by HuNoV or rotavirus, contributing to 0.5–15% of epidemic cases of non-bacterial gastroenteritis in humans [46]. They do contribute to a significant portion (up to 20%) of sporadic cases of viral gastroenteritis, especially among children under two years of age [46]. HAstV causes a mild infection in adults, which is often asymptomatic. Asymptomatic shedding in feces is estimated to be approximately 10% in most human populations, but as high as 30% prevalence rates have been reported in developing countries [46]. Co-infections with other enteric pathogens are common and have been reported to be between 17 and 65% [46]. In China, HuAstV detected in stools of children hospitalized with acute gastroenteritis has generally ranged from less than 1% to 8% [47]. In agreement with these findings, a seven-region study in China revealed a HAstV detection rate of 5.5% in the stools of hospitalized children under the age of five for diarrhea of 5.5%, with more than 95% of cases involving children under two years old [48]. Children and infants are very susceptible to HAstV infection because of their weak immunity protection, but sporadic cases among adults have also been detected in China in recent years [49].

Transmission of HAstV is by the fecal-oral route and occurs primarily person-to person. Outbreaks primarily occur in daycares, schools, nursing homes, hospitals, and military settings, with fomite contamination a factor implicated in transmission [50]. Although food- and water-borne outbreaks of HAstV are not major routes of transmission, there have been several reports of such events. One occurred in a school in Osaka, Japan in 1991, where thousands of students and staff from 14 schools were infected by HAstV after consumption of school lunches provided by a central food service [5]. HAstV was found to be responsible for an acute gastroenteritis outbreak in a maternity hospital in inner Mongolia, China, where 61 infants were diagnosed with acute gastroenteritis and 28 of 40 specimens were positive for HAstV; poor hygienic practices of reusing feeding bottles without adequate disinfection, sharing of bathwater among the infants, or inadequate environmental hygiene was thought to be the cause of this outbreak [51]. Shellfish are another source of food-borne HAstV infections, as demonstrated by HAstV detection in oyster tissues and clinical specimens associated with an outbreak of acute gastroenteritis involving several enteric viruses [7]. HAstV infections can occur due to water sanitation failures if untreated or inadequately treated wastewater is released into the environment. A one-year water quality study in Beijing, China revealed a 6.3% positive detection rate for HAstV in wastewater samples collected from sewage treatment plants [52].

8.2.5 Aichivirus

Aichiviruses (AiV-1) was first discovered in stool samples from patients having acute gastroenteritis after consuming raw oysters in Aichi, Japan in 1989 [53]. AiV-1 can cause acute gastroenteritis in humans. However, it is commonly associated with co-infections with other gastroenteritis-causing viruses, making its role as the causative agent of gastroenteritis difficult to discern. High seroprevalence rates with low virus detection rates suggests that the virus causes a primarily mild or asymptomatic infection. AiV-1 viruses can be shed in human feces, at concentrations up to 10^{12} viruses per g of feces [54] and transmitted via the oral-fecal route, through direct person-to-person contact or indirectly through consumption of contaminated foods or water. AiV-1 has been detected in stools, human sewage, reclaimed water, river water, and in shellfish worldwide, but has most often been detected in Japan [55]. Human sewage contamination of seawater is the major source of shellfish contamination by these viruses. Most AiV-1 outbreaks are associated with the consumption of raw shellfish. In Japan, AiV-1 was detected in 33% of 57 commercial packages of Japanese clams [6]. Aichiviruses were also among several enteric viruses identified in clinical specimens and oysters associated with a gastroenteritis outbreak in France [7]. Since it is often detected along with other viruses associated with gastrointestinal illness, its importance as a food- and water-borne pathogen is still unclear. Aichiviruses are a relatively newly discovered virus species, without extensive research to understand their pathology, epidemiology, and pathogenesis. The geography, demography, and seasonal pattern of AiV-1 infection are still unknown.

8.2.6 Hepatitis A Virus

The WHO estimates that there are 126 million cases of HAV globally each year and 35,000 deaths [56]. HAV infection is a globally widespread health problem, particularly in low-income countries where 90–100% of children are infected by the age of six [56]. Infection with HAV virus among children is typically asymptomatic and immunity is lifelong. In many middle- and high-income countries, the incidence of HAV infection has decreased due to improvements in sewage treatment and hygiene practices and vaccination programs. However, with increasing globalization of the food supply, consumption of HAV-contaminated foods imported from regions of the world where HAV is endemic has contributed to several large HAV outbreaks in high-income countries. In the United States, the majority of HAV illnesses (41%) are related to travel, but approximately 7% (1500 cases) each year are food-borne [16]. In addition, HAV is estimated to contribute to 31.5% of hospitalizations and 2.4% of deaths associated with food-borne illnesses [16]. Since widespread availability of a HAV vaccine in the mid to late 1990s, there has been a decrease in HAV infections in the US. Further decreases in HAV cases are likely since the vaccine has recently been incorporated into the US CDC's recommended childhood vaccine schedule.

HAV is transmitted predominantly through the fecal-oral route, primarily from person-to-person. In countries without access to good sanitation and where hygiene is poor, contaminated water is a major source of HAV infections [56]. There have been numerous reports of food-borne transmission of HAV, which has occurred due to food handler contamination or due to contact of the foods with fecally contaminated water. The largest outbreak of HAV reported to date occurred in China in 1988. Approximately 300 000 people became ill after consumption of raw or partially cooked clams growing in sewage-impacted water [58]. Shellfish-related outbreaks caused by HAV continue to occur globally. Fruits and vegetables contaminated with HAV via infected food handlers or contaminated irrigation or processing waters have also been the cause of outbreaks involving berries [57], frozen pomegranate seeds [59], semi-dried tomatoes [60], and green onions [61] in high-income countries throughout the world.

8.2.7 Hepatitis E Virus

HEV is a globally important cause of enterically transmitted acute hepatitis. In endemic regions of the world, HEV causes an estimated 20 million infections, 3.4 million symptomatic illnesses, 70 000 deaths, and 3000 stillbirths each year [62]. These infections primarily involve HEV1 and HEV2, and are particularly severe among pregnant women. In India alone, mortality estimates reach 1000 per year among pregnant women [62]. In China, India, and Africa, water-borne outbreaks and secondary person-to-person spread have involved thousands to even tens of thousands of persons [8,9]. Sources of HEV3 and HEV4 infections in developed countries are largely unrecognized, but evidence for zoonotic and food-borne transmission is emerging. The European Food Safety Authority now regards HEV as a significant emerging zoonotic and potential food-borne pathogen [63]. Discrepancies between seroprevalence and clinically confirmed cases suggest that asymptomatic infections and under-reporting are common.

HEV1 and HEV2 are transmitted predominantly by the fecal-oral route and are often involved in water-borne transmission. HEV3 and HEV4 are established zoonotic pathogens, transmitted through the consumption of raw or undercooked meat from certain animals (i.e., pig, deer, wild boar). Animal meat can become contaminated with HEV via infection of the liver or by contact with infected feces during animal dressing or meat processing. Retail pork products have recently been reported to be contaminated with HEV3 and HEV4 [10]. In several studies, a strong epidemiologic association between consumption of pork products and game meat [64], and deer [65] and human infections has been reported. Non-zoonotic sources of HEV3 and HEV4 infections have also been suggested by the contamination of water, shellfish, and fresh produce by swine or other animal waste [66]. Providing evidence for this, HEV has been detected on strawberries irrigated with river water under experimental conditions [41]. In additon, 1 of 38 samples of frozen raspberries tested positive for HEV in a study where enteric viruses were traced through a food production chain [67]; however, the source (water or human/animal contact) of HEV contamination could not be definitively identified.

8.3 The Current Status of Food-borne Viruses in China

The total disease and economic burden that food-borne viruses pose in China is not well understood. As with many countries, burden of disease statistics in China have not been accurately characterized. While surveillance programs for food-borne disease do exist in China, these programs are in their infancy, particularly in regard to food-borne viruses. The majority of food-borne virus outbreaks reported in China have been associated with either food handlers at the point of food service or shellfish grown in contaminated production waters. The majority of outbreaks involving food handlers have been associated with HuNoVs and those involving shellfish have been associated with HuNoV and/or HAV. Outbreaks involving fresh produce contaminated at the farm or during processing have not been reported domestically in China. However, a prominent HuNoV outbreak occurring in Germany involving imported strawberries from China highlights the potential for this contamination route to exist in China for both domestic and exported foods. International awareness about food-borne viruses is increasing. Concurrently, enhanced laboratory capabilities in recent years have allowed the development of national and international standards for food-borne virus detection, prevention, and control.

8.3.1 Food-borne Virus Surveillance in China

There are currently no national statistics available for food-borne virus prevalence in this expansive and diverse country. However, there are some recently published reports on enteric virus prevalence among hospitalized and/or outpatient children or adult populations experiencing severe diarrhea not necessarily associated with food contamination. The majority of these reports pertain to HuNoVs and/or rotaviruses and involve subjects residing within a single hospital, municipality, or Chinese province, with more information available in regions of high population density and middle- to high-income. Some recent examples include reports from Guangdong [68], Beijing [69], Huzhou city in the Zhejiang province [70], and Shenzhen city in the Guangdong province [30].

In 2014, Ahmed *et al.* [71] published a systematic review to estimate the global prevalence of HuNoVs, which included data from a previous systematic review by Patel *et al.* (2008) [72]. In this study, HuNoVs were associated with approximately 18% of acute gastroenteritis cases, globally. Detection rates were higher in community and outpatient settings than among hospitalized patients. The study included a high ratio of studies conducted in China (31 of 175 studies), but these studies tended to be small.

Since 2011, the Chinese government's active surveillance program for food-borne diseases has been updated and reorganized annually. The surveillance program includes food-borne disease (food poisoning included) reports, suspicious food-borne abnormal cases or abnormal health events, and active food-borne disease surveillance, including sentinel hospital detection, laboratory detection, case control studies, and special population surveillance for the elderly, infants, and immunocompromised persons [73]. Also in 2011, the nutrition and food safety department of the Chinese CDC published the first draft of a food-borne illness surveillance manual to establish systematic guidelines for hospital surveillance, laboratory detection, epidemiology, quality control, risk assessment, and prevention of food-borne illnesses [74]. The procedures for virus detection for certified laboratories are listed in this manual in detail and summarized in Table 8.2. Protocols specific for each method are also available on Foodmate.net.

Table 8.2 Standard methods for detection of food-borne viruses.

Virus	Standard method	Detection method	Sample type	Notes
Norovirus	SN/T 2730-2010	ELISA	Food for import and export	Abolished in Dec 2014
	SN/T 4055-2014	Conventional RT-PCR and real time RT-PCR	Shellfish	Implemented in May 2015
	SN/T 3841-2014	RT-LAMP	Exported shellfish	Implemented in Aug 2014
	SN/T 2626-2010	ELISA and RT-PCR	Feces, vomitus or food	Detection at frontier port
Sapovirus	SN/T 2531-2010	Conventional RT-PCR and real time RT-PCR	Shellfish and water	
Astrovirus	SN/T 2519-2010	Conventional RT-PCR and real time RT-PCR	Shellfish	
	SN/T 3841-2014	RT-LAMP	Exported shellfish	Implemented in Aug 2014
Aichivirus	Not available yet			
Rotavirus	SN/T 1720-2006	EM/PAGE/ELISA/ RT-PCR/AE/LA and CIA	Feces, vomitus, serologoical samples water or suspicious food samples	Codes of surveillance for rotavirus infection at entry-exit ports
	SN/T 2520-2010	Conventional RT-PCR and real time RT-PCR	Shellfish	Determination of group A Rotavirus
HAV	GB/T 22287-2008	Conventional RT-PCR and real time RT-PCR	Shellfish	
HEV	Not available yet			

Source: Summarized from Foodmate.net, 2015.

There are numerous regulations and policies regarding food-borne disease available in China, but very few pertain to food-borne viruses alone. In 2014, detection of HuNoV was included in the nationwide food safety inspection plan to further ensure the safety of consumption of fresh foods and shellfish [75]. Starting from 2005, the Chinese Ministry of Health established a food-borne virus surveillance group, responsible for the inspection and surveillance of food-borne viruses (HuNoV and rotavirus) in China. As a part of this group's activities, shellfish (marketed for raw consumption) are routinely inspected in selected provinces to better understand the epidemiology, transmission, and strain characteristics of food-borne viruses and to establish better prevention and control strategies to protect Chinese food and public health [75].

8.3.2 The Role of Food Handlers in Food-borne Virus Outbreaks in China

The role of foods in food-borne viral disease transmission is often complicated, since the majority of food-borne viruses are spread primarily via the person-to-person route. This is particularly evident among outbreaks with HuNoVs, due to their high transmissibility, attack rate, and propensity for secondary spread. It is often difficult to determine if the outbreak source is a food contaminated at the farm or during processing, a food handler preparing foods at the point of food service, or if person-to-person transmission is the source of an outbreak that is associated with foods.

An example of this latter point may be that serving utensils of a buffet could become contaminated by one user and upon handling by subsequent users, the virus is spread. Similarly, surfaces within a public bathroom contaminated by one user could become the source of viral transmission at a restaurant. Both of these examples involve fomite contamination, but do not directly involve food, even though they can be associated with a restaurant or catered setting. Also, food handlers are often reported to be asymptomatic at the time of food service. Outbreaks often involve food handlers that are either recovering from illness, pre-symptomatic (noted to experience symptoms 1–2 days after food service), or display a complete absence of symptoms (although virus shedding is confirmed by testing stools). Asymptomatic food handlers sometimes report caring for a sick infant or other family member in the home, even though they themselves do not report illness. Unfortunately, cases involving food handlers that have recovered from illness are common, particularly for HuNoVs, because the virus can be shed at high levels in feces for prolonged periods of time extending from days to even weeks [76]. It is for this reason that food workers experiencing gastrointestinal illness are to be excluded from direct food handling for 24 to 48 h after symptoms have subsided [77]. For those cases where a pre-symptomatic food handler is involved, it is often difficult to determine if the person was indeed shedding virus during the time of food service, or if they contracted the virus at the same time as the restaurant patrons through shared utensils, restrooms, or other surfaces, or by consumption of the same foods that were contaminated prior to handling.

Among the reported cases of HuNoV infection in China, the majority have occurred in schools or universities and have primarily implicated asymptomatic food handlers as the outbreak source. Examples of recent outbreaks include: an outbreak at a university in Guangzhou associated with an asymptomatic kitchen worker [78]; an outbreak among college students associated with asymptomatic food handlers at a delicatessen convenience store [79]; multiple HuNoV genotypes detected in clinical specimens from tourists linked to a restaurant [80]; an outbreak among students and teachers in a Shanghai boarding school associated with food handler contamination [81]; and an outbreak at a university following consumption of bread products contaminated by an asymptomatic food handler [82].

In major cities like Beijing, Shanghai, Guangzhou, and Shenzhen, HuNoV food-borne outbreaks have recently been linked to hygiene and sanitizing failures in school cafeterias and contaminated food consumption. Schools are often closed for several days for thorough disinfection, like the most recent HuNoV outbreak reported at a university in Shandong, China [83]. According to the Family Planning Bureau of Guangzhou reporting to the Guangzhou Daily News, starting in November 2014 to January 2015, there were 936 cases of HuNoV illnesses. Compared to the last few years, a lot more HuNoV outbreaks were experienced in the fall of 2014, involving mostly in kindergartens, elementary schools, middle/high schools, and universities. Most of the cases that year were confirmed to be due to consumption of contaminated foods [84].

In order to protect students from norovirus infection and decrease norovirus outbreaks in schools, the Department of Education of Guangdong province released an official guideline for schools to prevent and control norovirus outbreaks in December 2014 [85]. The guideline was the first official report in Guangdong providing detailed steps for school hygiene, food and water safety, tracking illnesses among school staff and students and recommendations for possible quarantine. Similarly, the Shanghai government released the Shanghai Norovirus Infection and Gastroenteritis Prevention and Control guidelines (Shanghai Qiyuan Shiyan Elementary school, 2014) in Dec 2014, to better detect and control HuNoVs outbreaks and to better document outbreaks for further surveillance and epidemiologic study [86]. This guideline was mainly distributed within schools, nursing homes, and local health departments in Shanghai to increase public awareness of HuNoVs and to protect individuals from infection.

8.3.3 Foods Contaminated by Food-borne Viruses During Production, Processing or Transport

Fresh produce and shellfish that are consumed raw are foods with the highest risk for food-borne virus contamination. Fresh produce can become contaminated prior to retail or food service via contaminated water used for irrigation, washing, or processing, by handlers during harvest, processing, or transport, or by infiltration of contaminated water onto farming areas by rain or flooding events. Contamination of shellfish is almost always related to contaminated production waters, although contamination through handling can occur. Since the majority of food-borne viruses are distinctly transmitted by humans, with the exception of HEV, which has a zoonotic route of transmission, hygiene failures and the lack of adequate sanitation and sewage treatment are the most frequently reported causes of fresh produce and shellfish contamination.

8.3.3.1 Shellfish

Shellfish contamination by viruses is problematic globally. China is one of the largest fish and shellfish producing countries in the world. The assurance of seafood safety is very important for domestic consumption and international trading [87]. Bivalve molluscan shellfish (oysters, clams, mussels, and cockles) are filter-feeders which can bio-concentrate enteric viruses in their digestive tissue. Since enteric viruses can persist in environmental water and in shellfish tissues for long periods of time, illnesses can result when shellfish are eaten raw or undercooked. Recent examples of studies where food-borne viruses have been detected in Chinese shellfish include: the presence of HuNoVs in retail shellfish from seven Chinese coastal cities [88]; HEV4 detection in shellfish from the Bohai Gulf of China [89]; and contamination by HAV, HuNoV, rotavius, astrovirus, and adenovirus detected in shellfish collected from the main coastal cities of China [90].

Although laws and regulations, such as the Chinese Fisheries Law, the Chinese Ocean and Environment Protection Law, and Seafood Harvesting Quality Standards have been established to regulate marine water quality and standards for shellfish growing and harvesting, comprehensive guidelines for industry and community usage are still needed, especially to regulate the treatment and release of treated human sewage for reducing enteric viruses from human sewage [91–93]. Seawater pollution in China has been very serious in recent years, leading to about 50% of coastline seawater areas unqualified for shellfish production and 5–8% of areas that have completely lost the ability to grow shellfish [87]. Seawater quality standards in China regulate that seawater for shellfish harvesting should be free from human pathogens, having a fecal coliform index of ≤ 10,000 colonies per liter (and ≤ 700 colonies per liter if shellfish grown in these areas are for raw consumption), but they do not include human enteric viruses in this regulation [94]. Unfortunately, there appears to be no direct correlation between the presence of enteric viruses and bacterial indicators due to the long persistence of viruses in shellfish [95].

8.3.3.2 Fresh Produce

Even when fresh produce is implicated as a source for food-borne illnesses, it can often be difficult to determine the source of its contamination. One example of this is the largest recorded food-borne outbreak of HuNoV, which was announced on Oct 2012 in Germany. It involved illness in 11 200 children and the vehicle was said to be frozen strawberries imported from China. While the majority of western news outlets claimed that the strawberries were contaminated with HuNoV in China, voices in China claimed innocence, stating that the strawberries produced in the same company were continuously tested with no traces of HuNoV being found. They stated that there was not enough evidence to draw conclusions that the contamination occurred in China and that the European claim contained bias and prejudice [96].

Following the incident, two papers have been published focusing on this event, one describing the epidemiological investigation and the other detailing the detection and typing of HuNoV procedures performed in the follow-up investigation [21,23]. Since three different genotypes of HuNoV were detected, the authors hypothesized that the strawberries may have been contaminated from water and the claim that a single infected food handler was responsible for the contamination was not rational [23]. As a result of this outbreak, a revision was made to the EU Regulation ((EC) No 669/2009), which sets out specifications for an increased level of official controls on imports of certain feed and food of non-animal origin, especially frozen strawberries from China. The Regulation, amended by the Commission Implementing Regulation (EU) No 1235/2012, requires that 5% of imports from China to be sampled and tested for the presence of HuNoVs and Hepatitis A viruses [97,98].

8.3.3.3 International Efforts for Food-borne Virus Detection, Prevention and Control

To date, there have been no other definitive reports or claims of food-borne virus contamination of fresh produce causing international or domestic outbreaks in China. However, increasing global awareness about food-borne viruses, enhanced laboratory capabilities for detecting viruses in foods and water, and improvements in international surveillance networks have all contributed to our ability to link food-borne virus outbreaks to fresh produce sources. Examples of international food-borne outbreaks detected within the last few years include; numerous outbreaks of HuNoV associated with berries [21,99] and lettuce [22], and HAV contamination of semi-dried tomatoes [60], frozen berries [57], and pomegranate aerils [59]. HEV transmission has only been reported to date to have occurred via contaminated water or through the consumption of meat from HEV-infected animals, although there is evidence of HEV contamination of fresh produce [41,67] and shellfish [89,100], and potential for outbreaks to occur as a result. Similarly, the other enteric viruses discussed in this chapter are shed in feces and contaminate water and hands, indicating the potential for future produce- and shellfish-related food-borne outbreaks due to these viruses.

The availability of standardized methods such as those put forth by the European Committee for Standardization (CEN) and the United States Food and Drug Administration (USFDA) for detecting viruses in different food types and in bottled water have enabled greater access to food and water testing by research and diagnostic laboratories. The CEN standard methods include the International Organization for Standardization (ISO) technical specification documents, ISO/TS 15216-1 and ISO/TS 15216-2, for hepatitis A and norovirus detection in foods and water by quantification and qualitative detection, respectively [101,102]. US Food and Drug Administration (FDA) has recently updated its Bacteriological Analytical Manual (BAM) to include protocols for Detection and Quantification of Hepatitis A Virus in Shellfish by the Polymerase Chain Reaction (FDA BAM method 26A) [103] and for Detection of Hepatitis A Virus in Foods (FDA BAM method 26B) [104]. National and international surveillance networks for enteric virus detection and epidemiology (including food-borne routes) have been established globally. Some prominent examples include the Food-borne Viruses in Europe Network (FBVE) and NoroNet, based at the National Institute for Public Health and the Environment (RIVM) in Europe, CaliciNet and the National Outbreak Reporting System (NORS), based at the Centers for Disease Control in the United States, the Infectious Disease Surveillance Center (IDSC) in Japan, and OzFoodNet in Australia. The development of standard methods for food-borne virus detection and the establishment of these national and international surveillance networks both increase the likelihood that an increasing number of outbreaks of food-borne viruses as a result of fresh produce contamination will be detected at national and even international scales.

After an initial Scientific Opinion update on the present knowledge on the occurrence and control of food-borne viruses by the European Food Safety Authority (EFSA) Panel on Biological Hazards [63], guidance documents for detection, prevention and control of HuNoV contamination of berries [105], leafy greens [106], and oysters [107] have been published. In addition, Codex Alimentarius recently published its document, "Guidelines on the Application of General Principles of Food Hygiene to the Control of Viruses in Food" (CAC/GL 79-2012) [108], which includes annexes for bivalve molluscs and fresh produce. These guidance documents provide important information for food producers, processors and retailers regarding the most current information about food-borne virus prevention and control. In addition, there have been several updated reviews on food-borne virus prevention and control strategies published recently, including the following topics: infection control of noroviruses targeting healthcare settings [109], the impact of food preservation methods on food-borne virus inactivation, [110] food processing technologies for inactivation of viruses in foods [111], and processing methods to inactivate viruses in shellfish [112].

8.4 Future Perspectives for Food-borne Viruses in China

Over the past two decades, many discoveries have been made which have enhanced our understanding of food-borne viruses. HuNoV and HAV in particular are now recognized as major pathogens of food-borne disease globally. HEV is also emerging as a prominent pathogen associated with zoonotic food-borne illnesses. Other enteric viruses, the majority of which cause gastroenteritis, have been known to be or are potential sources of food-borne illnesses and outbreaks. As our understanding of these viruses continues to increase, so too will our knowledge and ability to detect, prevent, and control them to enhance food safety and improve public health.

Although imperfect and still in its infancy, the creation of a national surveillance program for enteric virus detection and epidemiology in China is headed in the right direction. Large cities and heavily populated provinces have developed or are developing surveillance infrastructure for studying enteric virus prevalence and assessing outbreak sources. Epidemiologic investigations have revealed food-borne sources for some of these outbreaks, particularly those involving HuNoVs. However, compared to the US and Europe, research focusing on food-borne viruses in China is much less common. For the outbreaks of gastroenteritis that are reported, the source of infection and etiology is seldom known. Epidemiology studies of suspicious food-borne abnormal cases or abnormal health events are carried out only when more than three to five cases at the county level, more than 10 cases at the city level, more than 20 cases at the provincial level, more than 30 cases at the national level, or more than one case in two counties, two cities or two provinces occur at the same time [73].

Still, there are no comprehensive government food safety regulations specific for food-borne viruses in China. The transmission routes and treatment options for infection by food-borne viruses are different from infections by bacterial pathogens. In addition, hygiene practices, and sanitation and disinfection strategies for appropriate food-borne virus control are also distinct from those of bacterial food-borne pathogens. Governments at different levels in China and abroad have the responsibility to increase the safety of foods consumed domestically or exported. Regulations on sanitation and hygiene practices appropriate for food-borne viruses from the farm to industry and into homes are thus needed. Outreach and education to the public is also needed.

As in many countries, the general public’s education and awareness about food-borne viruses in China is insufficient, especially among high-risk populations such as children, the elderly, and immune-compromised patients who often suffer the most severe disease outcomes. However, a small number of websites, videos, and news outlets discuss food-borne viruses, particularly HuNoVs. For instance, in October 2014, the General Office of National Health and Family Planning Commission and the Ministry of Education announced a program to strengthen school food-borne disease surveillance and drinking water hygiene management. It stated that the local health and family planning commissions should closely cooperate with schools to promote training and awareness about food-borne diseases and drinking water hygiene [113]. One example of successful communication and implementation of this policy was an education campaign carried out in Jin Keng elementary school in December 2014 [114].

Currently, within the Chinese National Knowledge Infrastructure (CNKI) database, which is considered the largest and most comprehensive, as well as authoritative source of China-based information in the world, publications with a direct focus on food-borne viruses are limited. Thousands of papers have been published on viral diarrhea surveillance based on data collected on the city or provincial level. In addition, papers analyzing data from food-borne disease outbreak surveillance are also common. In the CNKI database, the number of existing publications about food-borne viruses is listed in Table 8.3 with a comparison to the number of publications listed for specific enteric viruses in China. Also of note, a uniform nomenclature for HuNoV was not established in China until 2009. Thus when tracing back to past publications of HuNoV, multiple Chinese words referencing different naming conventions were needed. This strategy was used when extracting the data for Table 8.3.

In conclusion, knowledge and awareness about food-borne viruses is growing in China and globally. Many improvements in enteric virus and food-borne pathogen surveillance, as well as public health infrastructure have been made in recent years in China, particularly in highly populated and economically advanced municipalities and provinces. Yet, there is still much room for improvement regarding public awareness and government regulation of food-borne viruses. There is also much disparity in China regarding public health programs in urban versus rural areas. More research, public health programs, and government policies are needed to enable further understanding

Table 8.3 Number of publications describing enteric or food-borne viruses when keywords were searched in the China National Knowledge Infrastructure (CNKI) database.

Keyword	Publications	Earliest year
Food-borne virus	12	1999
Norovirus	1240	1982
HAV	1218	1975
HEV	1288	1990
Sapovirus	10	2008
Astrovirus	470	1980
Aichivirus	3	2010
Rotavirus	7606	1977
Adenovirus	5323	1959

Source: Summarized from CNKI, 2015.
Date compiled: 3/27/2015.

of the disease burden of food-borne viruses in China and to better protect the safety of its foods and the health of its people. China is not alone in this need, which is echoed throughout countries of the world.

References

1 Hu, R., 2007, Foodborne disease current status and control strategies in China, *J. Publ. Health Prevent. Med.* 18(3):55–56.

2 Koopmans, M., 2012, *Food-borne viruses from a global perspective, in Improving Food Safety Through a One Health Approach: Workshop Summary*. Rapporteurs: Choffnes, E.R, Olsen, L.A., Hutton, H., and Mack, A., National Academies Press (US), Washington (DC):225–251.

3 Yamashita, Y., Ootsuka, Y., Kondo, R., Oseto, M., Doi, M., Miyamoto, T., Ueda, T., Kondo, H., Tanaka, T., Wakita, T., Katayama, K., Takeda, N., and Oka, T., 2010, Molecular characterization of sapovirus detected in a gastroenteritis outbreak at a wedding hall, *J. Med. Virol.* 82:720–726.

4 Kobayashi, S., Fujiwara, N., Yasui, Y., Yamashita, T., Hiramatsu, R., and Minagawa, H., 2012, A foodborne outbreak of sapovirus linked to catered box lunches in Japan, *Arch. Virol.* 157:1995–1997.

5 Oishi, I., Yamazaki, K., Kimoto, T., Minekawa, Y., Utagawa, E., Yamazaki, S., Inouye, S., Grohmann, G.S., Monroe, S.S., Stine, S.E., *et al.*, 1994, A large outbreak of acute gastroenteritis associated with astrovirus among students and teachers in Osaka, Japan, *J. Infect. Dis.* 170:439–443.

6 Hansman, G.S., Oka, T., Li, T.C., Nishio, O., Noda, M., and Takeda, N., 2008, Detection of human enteric viruses in Japanese clams, *J. Food Prot.* 71:1689–695.

7 Le Guyader, F.S., Le Saux, J.C., Ambert-Balay, K., Krol, J., Serais, O., Parnaudeau, S., Giraudon, H., Delmas, G., Pommepuy, M., Pothier, P., and Atmar, R.L., 2008, Aichi virus, norovirus, astrovirus, enterovirus, and rotavirus involved in clinical cases from a French oyster-related gastroenteritis outbreak, *J. Clin. Microbiol.* 46:4011–4017.

8 CDC, Centers for Disease Control and Prevention, 2013, Investigation of hepatitis E outbreak among refugees - upper Nile, South Sudan, 2012–2013, *Morb. Mortal. Wkly. Rep.* 62:581–586.

9 Kamar, N., Bendall, R., Legrand-Abravanel, F., Xia, N.S., Ijaz, S., Izopet, J., and Dalton, H.R., 2012, Hepatitis E, *Lancet* 379:2477–2488.

10 Colson, P., Borentain, P., Queyriaux, B., Kaba, M., Moal, V., Gallian, P., Heyries, L., Raoult, D., and Gerolami, R., 2010, Pig liver sausage as a source of hepatitis E virus transmission to humans, *J. Infect. Dis.* 202:825–834.

11 Wong, K., Fong, T.T., Bibby, K., and Molina, M., 2012, Application of enteric viruses for fecal pollution source tracking in environmental waters, *Environ. Intnl.* 45:151–164.

12 Döbbecker, B., Dobler, G., Spiegel, M. and Hufert, F.T., 2010, Tick-borne encephalitis virus and the immune response of the mammalian host, *Travel Med. and Infect. Dis.* 8:213–222.

13 Graham, R.L. and Baric, R.S., 2010, Recombination, reservoirs, and the modular spike: mechanisms of coronavirus cross-species transmission, *J. Virol.* 84:3134–3146.

14 Milne-Price, S., Miazgowicz, K.L., and Munster, V.J., 2014, The emergence of the Middle East Respiratory Syndrome coronavirus (MERS-CoV), *Pathog. Dis.* 71:119–134.

15 Duizer, E., and Koopmans, M., 2008, Emerging food-borne viral diseases, in: *Food-Borne Viruses: Progress and Challenges.* (M. Koopmans, D.O. Cliver, and A. Bosch, eds.), ASM Press, Washington, DC, pp. 117–145.

16 Scallan, E., Hoekstra, R.M., Angulo, F.J., Tauxe, R.V., Widdowson, M.A., Roy, S.L., Jones, J.L., and Griffin, P.M., 2011, Foodborne illness acquired in the United States-major pathogens, *Emerg. Infect. Dis.* 17:7–15.

17 Scharff R.L., 2012, Economic burden from health losses due to foodborne illness in the United States. *J. Food Protect.*,75(1):123–131.

18 Verhoef, L., Vennema, H., van Pelt, W., Lees, D., Boshuizen, H., Henshilwood, K., and Koopmans, M., 2010, Use of norovirus genotype profiles to differentiate origins of foodborne outbreaks, *Emerg. Infect. Dis.* 16:617–624.

19 Greening, G.E., Hewitt, J., Rivera-Aban, M., and Croucher, D., 2012, Molecular epidemiology of norovirus gastroenteritis outbreaks in New Zealand from 2002–2009, *J. Med. Virol.* 84:1449–1458.

20 Hall, A.J., Eisenbart, V.G., Etingue, A.L., Gould, L.H., Lopman, B.A., and Parashar, U.D., 2012, Epidemiology of foodborne norovirus outbreaks, United States, 2001–2008, *Emerg. Infect. Dis.* 18:1566–1573.

21 Bernard, H., Faber, M., Wilking, H., Haller, S., Höhle, M., Schielke, A., Ducomble, T., Siffczyk, C., Merbecks, S. S., Fricke, G., Hamouda, O., Stark, K., Werber, D., 2014, Large multistate outbreak of norovirus gastroenteritis associated with frozen strawberries, Germany, 2012, *Eurosurveill.* 19(8): 1–9.

22 Ethelberg, S., Lisby, M., Bottiger, B., Schultz, A.C., Villif, A., Jensen, T., Olsen, K.E., Scheutz, F., Kjelso, C., and Muller, L., 2010, Outbreaks of gastroenteritis linked to lettuce, Denmark, January 2010, *Eurosurveill.* 15:2–4.

23 Mäde, D., Trubner, K., Neubert, E., Hohne, M., and Johne, R., 2013, Detection and typing of norovirus from frozen strawberries involved in a large-scale gastroenteritis outbreak in Germany, *Food Environ. Virol.* 5:162–168.

24 Maunula, L., Roivainen, M., Keranen, M., Makela, S., Soderberg, K., Summa, M., von Bonsdorff, C.H., Lappalainen, M., Korhonen, T., Kuusi, M., and Niskanen, T., 2009, Detection of human norovirus from frozen raspberries in a cluster of gastroenteritis outbreaks, *Eurosurveill.* 14:16–18.

25 Summa, M., von Bonsdorff, C.H., and Maunula, L., 2012, Pet dogs: A transmission route for human noroviruses? *J. Clin. Virol.* 53:244–247.

26 Tan, M., and Jiang, X., 2010, Norovirus gastroenteritis, carbohydrate receptors, and animal models, *PLoS Path.* 6(8): e1000983.

27 Oka, T., Wang, Q., Katayama, K., and Saif, L.J., 2015, Comprehensive review of human sapoviruses, *Clin. Microbiol. Rev.* 28:32–53.

28 Lee, L.E., Cebelinski, E.A., Fuller, C., Keene, W.E., Smith, K., Vinje, J., and Besser, J.M., 2012, Sapovirus outbreaks in long-term care facilities, Oregon and Minnesota, USA, 2002–2009, *Emerg. Infect. Dis.* 18:873–876.

29 Lu, L., Jia, R., Zhong, H., Xu, M., Su, L., Cao, L., Dong, Z., Dong, N., and Xu, J., 2015, Molecular characterization and multiple infections of rotavirus, norovirus, sapovirus, astrovirus and adenovirus in outpatients with sporadic gastroenteritis in Shanghai, China, 2010-2011, *Arch. Virol.* 160(5):1229–1238.

30 Wu, W., Yang, H., Zhang, H. L., Xian, H. X., Yao, X. J., Zhao, D. J., Chen, L., Shu, B.H., Zhou, Y.K., He, Y. Q., 2014, Surveillance of pathogens causing gastroenteritis and characterization of norovirus and sapovirus strains in Shenzhen, China, during 2011, *Arch. Virol.* 159(8):1995–2002.

31 Noel, J.S., Liu, B.J., Humphrey, C.D., Rodriguez, E.M., Lambden, P.R., Clarke, I.N., Dwyer, D.M., Ando, T., Glass, R.I., and Monroe, S.S., 1997, Parkville virus: A novel genetic variant of human calicivirus in the sapporo virus clade, associated with an outbreak of gastroenteritis in adults, *J. Med. Virol.* 52:173–178.

32 Ueki, Y., Shoji, M., Okimura, Y., Miyota, Y., Masago, Y., Oka, T., Katayama, K., Takeda, N., Noda, M., Miura, T., Sano, D., and Omura, T., 2010, Detection of sapovirus in oysters, *Microbiol. Immunol.* 54:483–486.

33 Scheuer, K.A., Oka, T., Hoet, A.E., Gebreyes, W.A., Molla, B.Z., Saif, L.J., and Wang, Q., 2013, Prevalence of porcine noroviruses, molecular characterization of emerging porcine sapoviruses from finisher swine in the United States, and unified classification scheme for sapoviruses, *J. Clin. Microbiol.* 51:2344–2353.

34 Parashar, U.D., Gibson, C.J., Bresee, J.S., and Glass, R.I., 2006, Rotavirus and severe childhood diarrhea, *Emerg. Infect. Dis.* 12:304–306.

35 Glass, R.I., Patel, M., and Parashar, U., 2011, Lessons from the US rotavirus vaccination program, *JAMA* 306:1701–1702.

36 Motarjemi, Y., Kaferstein, F., Moy, G., and Quevedo, F., 1993, Contaminated weaning food: A major risk factor for diarrheoea and associated malnutrition, *Bull. World Health Org.* 71:79–92.

37 CDC, Centers for Disease Control and Prevention, 2000, Foodborne outbreak of group A rotavirus gastroenteritis among college students-District of Columbia, March-April 2000, *Morb. Mortal. Wkly. Rep.* 49:1131–1133.

38 Iizuka, S., Matsuda, Y., Hoshina, K., and Itagaki, A., 2000, *An outbreak of group A rotavirus infection among adults from eating meals prepared at a restaurant, April 2000, Shimane, in IASR, Infectious Agents Surveillance Report*, 21st ed. Shimane Prefectural Institute of Public Health and Environmental Science, pp. 145–146.

39 Hernandez, F., Monge, R., Jimenez, C., and Taylor, L., 1997, Rotavirus and hepatitis A virus in market lettuce (*Latuca sativa*) in Costa Rica, *Int. J. Food Microbiol.* 37:221–223.

40 Felix-Valenzuela, L., Resendiz-Sandoval, M., Burgara-Estrella, A., Hernandez, J., and Mata-Haro, V., 2012, Quantitative detection of hepatitis A, rotavirus and genogroup I norovirus by RT-qPCR in fresh produce from packinghouse facilities, *J. Food Safety* 32:467–473.

41 Brassard, J., Gagne, M.J., Genereux, M., and Cote, C., 2012, Detection of human food-borne and zoonotic viruses on irrigated, field-grown strawberries, *Appl. Environ. Microbiol.* 78:3763–3766.

42 Koroglu, M., Yakupogullari, Y., Otlu, B., Ozturk, S., Ozden, M., Ozer, A., Sener, K., and Durmaz, R., 2011, A waterborne outbreak of epidemic diarrhea due to group A rotavirus in Malatya, Turkey, *New Microbiol.* 34:17–24.

43 Hung, T., Chen, G.M., Wang, C.G., Yao, H.L., Fang, Z.Y., Chao, T.X., Chou, Z.Y., Ye, W., Chang, X.J., Den, S.S., and Chang, W.C., 1984, Waterborne outbreak of rotavirus diarrhoea in adults in China caused by a novel rotavirus, *Lancet* 1:1139–1142.

44 Ming, H.X., Fan, J.F., Wu, L.J., and Liang, Y.B., 2013, Prevalence of human enteric viruses and a potential indicator of contamination in shellfish in China, *J. Food Safety* 33:209–214.

45 Martella, V., Banyai, K., Matthijnssens, J., Buonavoglia, C., and Ciarlet, M., 2010, Zoonotic aspects of rotaviruses, *Vet. Microbiol.* 140:246–255.

46 De Benedictis, P., Schultz-Cherry, S., Burnham, A., and Cattoli, G., 2011, Astrovirus infections in humans and animals - molecular biology, genetic diversity, and interspecies transmissions, *J. Molec. Epidemiol. Evol. Genetic Infect. Dis.* 11:1529–1544.

47 Zhang, Y.H., Luo, X.F., Wang, Q., Zhu, X.J., Huang, L., Qiu, Y., Yang, L.Z., and Lu, X.D., 2011, Analysis of astrovirus infection in 413 infants with acute diarrhea in Shenzhen City, *China Trop. Med.* 7, 803–805.

48 Fang, Z.Y., Sun, Y.P., Ye, X.H., Wang, H., Zhang, Q., Duan, Z.J., Xi, J., Steele, D., and Glass, R., 2006, Astrovirus infection among hospitalized children with acute diarrhea in seven regions of China, 1998-2005, *Zhonghua Liu Xing Bing Xue Za Zhi* 27(8), 673–676.

49 Xu, Q.H., Tang, Y.L., Nie, J., Cai, L.G., Li, J.D., Dai, Y.C., Chen, Q., and Yu, S.Y., 2008, Detection and genotyping of astrovirus in adults with gastroenteritis in Jiangmen. *J. Trop. Med* 8(5), 420–423.

50 Bosch, A., Pintó, R.M.,and Guix, S., 2014, Human astroviruses, *Clin. Microbiol. Rev.* 27:1048–1074.

51 Li, C.Y., Liu, N., Guo, W.D., Yu, Q., Wang, W.R., Song, Z.Z., Yan, H., Luo, Y., Lu, A.T., Li, H.Y., Zhu, L., and Duan, Z.J., 2010, Outbreak of neonatal gastroenteritis associated with astrovirus serotype 1 at a hospital in Inner Mongolia, China, *J. Clin. Microbiol.* 48(11):4306–4309.

52 He, X.Q., Cheng, L., Zhang, D.Y., Xie, X.M., Wang, D.H., and Wang, Z., 2011, One-year monthly survey of rotavirus, astrovirus and norovirus in three sewage treatment plants in Beijing, China and associated health risk assessment, *Water Sci. Technol.* 63(1):191–198.

53 Yamashita, T., Kobayashi, S., Sakae, K., Nakata, S., Chiba, S., Ishihara, Y., and Isomura, S., 1991, Isolation of cytopathic small round viruses with BS-C-1 cells from patients with gastroenteritis, *J. Infect. Dis.* 164:954–957.

54 Drexler, J.F., Baumgarte, S., de Souza Luna, L.K., Eschbach-Bludau, M., Lukashev, A.N., and Drosten, C., 2011, Aichi virus shedding in high concentrations in patients with acute diarrhea, *Emerg. Infect. Dis.* 17(8):1544–1548.

55 Kitajima, M. and Gerba, C.P., 2015, Aichivirus 1: environmental occurance and behavior, *Pathogens* 4(2):256–268.

56 Aggarwal, R. and Goel, A., 2015, Hepatitis A: epidemiology in resource-poor countries, *Curr. Opin. Infect. Dis.* 28(5):488–496.

57 Fitzgerald, M., Thornton, L., O’ Gorman, J., O’ Connor, L., Garvey, P., Boland, M., Part, A.M., Rogalska, J., Coughlan, H., MacDiarmada, J., Heslin, J., Canny, M., Finnegan, P., Moran, J., O’Flanagan, D.; Hepatitis A Outbreak Control Team, 2014, Outbreak of hepatitis A infection associated with the consumption of frozen berries, Ireland, 2013: linked to an international outbreak, *Eurosurveill.* 19(43), pii:20942.

58 Halliday, M.L., Kang, L.Y., Zhou, T.K., Hu, M.D., Pan, Q.C., Fu, T.Y., Huang, Y.S., and Hu, S.L., 1991, An epidemic of hepatitis A attributable to the ingestion of raw clams in Shanghai, China, *J. Infect. Dis.* 164:852–859.

59 *Anonymous, 2013, Multistate outbreak of hepatitis A virus infections linked to pomegranate seeds from Turkey (final update).* Centers for Disease Control and Prevention. Posted October 28, 2008. http://www.cdc.gov/hepatitis/outbreaks/2013/a1b-03-31/index.html. Accessed March 13, 2014.

60 Donnan, E.J., Fielding, J.E., Gregory, J.E., Lalor, K., Rowe, S., Goldsmith, P., Antoniou, M., Fullerton, K.E., Knope, K., Copland, J.G., Bowden, D.S., Tracy, S.L., Hogg, G.G., Tan, A., Adamopoulos, J., Gaston, J., and Vally, H., 2012, A multistate outbreak of hepatitis A associated with semidried tomatoes in Australia, 2009, *Clin. Infect. Dis.* 54:775–781.

61 CDC, Centers for Disease Control and Prevention, 2003, Hepatitis A outbreak associated with green onions at a restaurant: Monaca, Pennsylvania, 2003, *Morbid. Mortal. Weekly Rep.* 52:1155–1157.

62 Dalton, H.R., Hunter, J.G., and Bendall, R.P., 2013, Hepatitis E, *Current Opin. Infect. Dis.* 26:471–478.

63 EFSA, European Food Safety Authority, Panel on Biological Hazards (BIOHAZ), 2011, Scientific Opinion on an update on the present knowledge on the occurrence and control of foodborne viruses, *EFSA J.* 9(7):2190.

64 Li, T.C., Chijiwa, K., Sera, N., Ishibashi, T., Etoh, Y., Shinohara, Y., Kurata, Y., Ishida, M., Sakamoto, S., Takeda, N., and Miyamura, T., 2005, Hepatitis E virus transmission from wild boar meat, *Emerg. Infect. Dis.* 11:1958–1960.

65 Tei, S., Kitajima, N., Takahashi, K., and Mishiro, S., 2003, Zoonotic transmission of hepatitis E virus from deer to human beings, *Lancet* 362:371–373.

66 Meng, X.J., 2011, From barnyard to food table: The omnipresence of hepatitis E virus and risk for zoonotic infection and food safety, *Virus Res.* 161:23–30.

67 Maunula, L., Kaupke, A., Vasickova, P., Soderberg, K., Kozyra, I., Lazic, S., van der Poel, W.H., Bouwknegt, M., Rutjes, S., Willems, K.A., Moloney, R., D'Agostino, M., de Roda Husman, A.M., von Bonsdorff, C.H., Rzezutka, A., Pavlik, I., Petrovic, T., and Cook, N., 2013, Tracing enteric viruses in the European berry fruit supply chain, *Int. J. Food Microbiol.* 167:177–185.

68 Lu, J., Sun, L.M., Fang, L., Yang, F., Mo, Y.L., Lao, J.Q., Zheng, H.Y., Tan, X.H., Lin, H.L., Rutherford, S., Guo, L.L., Ke, C.W., and Hui, L., 2015a, Gastroenteritis outbreaks caused by norovirus GII. 17, Guangdong Province, China, 2014–2015, *Emerg. Infect. Dis.* 21:1240–1242.

69 Tian, G., Jin, M., Li, H., Li, Q., Wang, J., and Duan, Z. J., 2014, Clinical characteristics and genetic diversity of noroviruses in adults with acute gastroenteritis in Beijing, China in 2008–2009, *J. Med. Virol.* 86(7):1235–1242.

70 Wu, X.F., Han, J.K., Chen, L.P., Xu, D.S., Shen, Y.H., Zha, Y.F., Zhu, X.J., and Ji, L., 2015, Prevalence and genetic diversity of noroviruses in adults with acute gastroenteritis in Huzhou, China, 2013–2014, *Arch. Virol.* 2015:1–9.

71 Ahmed, S.M., Hall, A.J., Robinson, A.E., Verhoef, L., Premkumar, P., Parashar, U.D., Koopmans, M., and Lopman, B.A., 2014, Global prevalence of norovirus in cases of gastroenteritis: a systematic review and meta-analysis, *Lancet Infect. Dis.* 14(8):725–730.

72 Patel, M.M., Widdowson, M.A., Glass, R.I., Akazawa, K., Vinjé, J., and Parashar, U.D., 2008, Systematic literature review of role of noroviruses in sporadic gastroenteritis, *Emerg. Infect. Dis.* 14(8):1224–1231.

73 CCDC, Chinese Center for Disease Control and Prevention, National Institute for Nutrition and Health, 2013, Foodborne disease active surveillance handbook for 2013 (2013年食源性疾病监测计划).

74 CCDC, Chinese Center for Disease Control and Prevention, National Institute for Nutrition and Health, 2011, Foodborne disease active surveillance handbook for 2011-2012 (2011-2012食源性疾病主动监测工作手册).

75 CFDA, China Food and Drug Administration, 2015, Scientific interpretation of norovirus (关于诺如病毒的科学解读). http://www.sfda.gov.cn/WS01/CL1679/114664.html. Accessed April 10, 2015.

76 Atmar, R.L., Opekun, A.R., Gilger, M.A., Estes, M.K., Crawford, S.E., Neill, F.H., and Graham, D.Y., 2008, Norwalk virus shedding after experimental human infection, *Emerg. Infect. Dis.* 14:1553–1557.

77 USFDA, U.S. Food and Drug Administration. Food Code 2009: Chapter 2 – Management and Personnel. http://www.fda.gov/Food/GuidanceRegulation/RetailFoodProtection/FoodCode/ucm181242.htm. Accessed August 4, 2014.

78 Cai, W.F., Xie, H.P., Liu, Y.F., Yuan, J., Xiao, X.C., Ding, P., Chen, C., Zhang, D., Chen, J.D., Ma, X.W., Geng, J.M., Lin, D.M., Lian, G.X., and Yang, Z.C., 2013, An epidemiological investigation on a food-born outbreak of norovirus caused by Sydney 2012 GII.4 strain, *Zhonghua Liu Xing Bing Xue Za Zhi*, 34(8):804–807.

79 Ruan, F., Tan, A.J., Man, T.F., Li, H., Mo, Y.L., Lin, Y.X., and Deng, X.L., 2013, Gastroenteritis outbreaks caused by Norovirus genotype II.7 in a college in China (Zhuhai, Guangdong) in 2011, *Foodborne Pathog. Dis.* 10(10):856–860.

80 Huang, J., Xu, X., Weng, Q., Hong, H., Guo, Z., He, S., and Niu, J., 2013, Serial foodborne norovirus outbreaks associated with multiple genotypes, *PLoS One* 8(5):e63327.

81 Xue, C., Fu, Y., Zhu, W., Fei, Y., Zhu, L., Zhang, H., Pan, L., Xu, H., Wang, Y., Wang, W., and Sun, Q., 2014, An outbreak of acute norovirus gastroenteritis in a boarding school in Shanghai: a retrospective cohort study, *BMC Publ. Health* 14:1092.

82 Guo, Z., Huang, J., Shi, G., Su, C.H., and Niu, J.J., 2014, A food-borne outbreak of gastroenteritis caused by norovirus GII in a university located in Xiamen City, China, *Int. J. Infect. Dis.* 28:101–106.

83 News.china.com, 2015, *Shandong High School 654 children infected with norovirus*. http://news.china.com/domestic/945/20150620/19877984.html?qq-pf-to=pcqq.group. Accessed online June 21, 2015.

84 Ren, W., 2015, Present cases of norovirus have grown in severity compared to previous years, *Guangzhou Daily News*, Guangzhou, China. http://gzdaily.dayoo.com/html/2015-01/24/content_2850726.htm. Accessed July 20, 2015.

85 Gdhed.edu, 2014, *Guangdong announcement of virus workers*. http://www.gdhed.edu.cn/business/htmlfiles/gdjyt/tzgg/201412/482628.html. Accessed July 20, 2015.

86 Shanghai Qiyuan Shiyan Elementary school, 2014. *Shanghai Norovirus Infection and Gastroenteritis Prevention and Control guidelines*. http://xxgk.zb.edu.sh.cn/3101080006/8126-5. Accessed July 20, 2015.

87 MEP, Ministry of Environmental protection, the People's Republic of China, 2013. http://www.mep.gov.cn/gkml/hbb/bgth/201312/t20131224_265489.htm. Accessed July 20, 2015.

88 Ma, L.P., Zhao, F., Yao, L., Li, X.G., Zhou, D.Q. and Zhang, R.L., 2013, The presence of genogroup II norovirus in retail shellfish from seven coastal cities in China, *Food Environ. Virol.* 5(2):81–86.

89 Gao, S., Li, D., Zha, E., Zhou, T., Wang, S., and Yue, X., 2015, Surveillance of hepatitis E virus contamination in shellfish in China, *Intnl. J. Environ. Res. Public Health* 12:2026–2036.

90 Ming, H., Fan, J., Wu, L., Yue, L., Gao, X., and Liang, Y., 2014, Contamination of typical human enteric viruses in economic shellfish along the Chinese coast, *Wei Sheng Wu Xue Bao* 54(1):69–79.

91 NPC, National People's Congress of the People's Republic of China, 1986. *Seafood cultivation Law*. http://www.npc.gov.cn/wxzl/gongbao/2000-12/06/content_5004465.htm. Accessed July 20, 2015.

92 NPC, National People's Congress of the People's Republic of China, 1999. http://www.npc.gov.cn/wxzl/wxzl/2008-12/15/content_1462092.htm. Accessed July 20, 2015.

93 MOA, Ministry of Agriculture of the People's Republic of China, 2003. *Seafood safety regulation*. http://www.moa.gov.cn/zwllm/tzgg/bl/200308/t20030813_109779.htm. Accessed July 20, 2015.

94 MEP, Ministry of Environmental protection, the People's Republic of China, 1998, Sea water quality standard, China, GB 3097-1997. http://english.mep.gov.cn/standards_reports/standards/water_environment/quality_standard/200710/t20071024_111791.htm. Accessed July 20, 2015.

95 Richards, G.P., 2016, *Chapter 7: Shellfish-associated enteric virus illness: virus localization, disease outbreaks and prevention, in Viruses in Foods*, (Goyal, S. and Cannon, J.L., eds.) Springer Science and Business Media, LLC, New York, NY.

96 Pheonix TV, 2012, *Germany indicated Chinese strawberry is not safe*. http://phtv.ifeng.com/program/zbjsj/detail_2012_10/12/18210549_0.shtml. Accessed July 21, 2015.

97 EU, European Union, 2009, Commission Implementing Regulation (EU) No. 669/2009. *Official Journal of the European Union*. July 24, 2009. http://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX:32009R0669. Accessed August 4, 2014.

98 EU, European Union, 2012, Commission Implementing Regulation (EU) No. *1235/2012. Official Journal of the European Union.* Dec. 19, 2012. http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2012:350:0044:0050:EN:PDF. Accessed August 4, 2014.

99 Sarvikivi, E., Roivainen, M., Maunula, L., Niskanen, T., Korhonen, T., Lappalainen, M., and Kuusi, M., 2012, Multiple norovirus outbreaks linked to imported frozen raspberries, *Epidemiol. Infect.* 140:260–267.

100 Crossan, C., Baker, P.J., Craft, J., Takeuchi, Y., Dalton, H.R., and Scobie, L., 2012, Hepatitis E virus genotype 3 in shellfish, United Kingdom, *Emerg. Infect. Dis.* 18:2085–2087.

101 ISO, International Organization for Standardization, 2013, *ISO/TS 15216-1:2013: Microbiology of food and animal feed -- Horizontal method for determination of hepatitis A virus and norovirus in food using real-time RT-PCR -- Part 1: Method for quantification*. http://www.iso.org/iso/catalogue_detail.htm?csnumber=55382. Accessed 24 October 2016.

102 ISO, International Organization for Standardization, 2013b, *ISO/TS 15216-1:2013: Microbiology of food and animal feed -- Horizontal method for determination of hepatitis A virus and norovirus in food using real-time RT-PCR -- Part 2: Method for qualitative detection*. http://www.iso.org/iso/iso_catalogue/catalogue_tc/catalogue_detail.htm?csnumber=60297. Accessed 24 October 2016.

103 USFDA, U.S. Food and Drug Administration, 2015a, *Bacteriological Analytical Manual (BAM), Method 26A: Detection and quantification of hepatitis A virus in shellfish by the polymerase chain reaction*. http://www.fda.gov/Food/FoodScienceResearch/LaboratoryMethods/ucm2006949.htm. Accessed August 4, 2015

104 USFDA, U.S. Food and Drug Administration, 2015b, *Bacteriological Analytical Manual (BAM), Method 26B: Detection of hepatitis A virus in foods*. http://www.fda.

gov/Food/FoodScienceResearch/LaboratoryMethods/ucm2006949.htm. Accessed August 4, 2015

105 EFSA, European Food Safety Authority, Panel on Biological Hazards (BIOHAZ), 2014a, Scientific Opinion on the risk posed by pathogens in food of non-animal origin. Part 2 (Salmonella and Norovirus in berries), *EFSA J.* 12(6):3706.

106 EFSA, European Food Safety Authority, Panel on Biological Hazards (BIOHAZ), 2014b, Scientific Opinion on the risk posed by pathogens in food of non-animal origin. Part 2 (Salmonella and Norovirus in leafy greens eaten raw as salads), *EFSA J.* 12(3):3600.

107 EFSA, European Food Safety Authority, Panel on Biological Hazards (BIOHAZ), 2012, Scientific Opinion on Norovirus (NoV) in oysters: methods, limits and control options, *EFSA J.* 10(1);2500.

108 Codex Alimentarious, 2012, Guidelines on the Application of General Principles of Food Hygiene to the Control of Viruses in Food (CAC/GL 79-2012) at http://www.codexalimentarius.org/standards/list-of-standards/ Accessed Augusr 4, 2014.

109 Hall, A.J., Vinjé, J., Lopman, B., Park, G.W., Yen, Catherine, Gregoricus, N. and Parashar, U., 2011, Updated norovirus outbreak management and disease prevention guidelines, *MMWR* 60:1–15.

110 Baert, L., Debevere, J. and Uyttendaele, M., 2009, The efficacy of preservation methods to inactivate foodborne viruses, *Int. J. Food Microbiol.* 131:83–94.

111 Hirneisen, K.A., Black, E.P., Cascarino, J.L., Fino, V.R., Hoover, D.G. and Kniel, K.E., 2010, Viral inactivation in foods: A comprehensive review of traditional and novel food-processing technologies, *Comp. Rev. Food Sci. Food Safe.* 1:3–20.

112 Richards, G.P., McLeod, C., and Le Guyader, F.S., 2010, Processing strategies to inactivate enteric viruses in shellfish, *Food Environ. Virol.* 3:183–193.

113 NHFPC, National Health and Family Planning Commission, 2014, *NHFPC and MOE Joint Announcement on Strengthening Management of School Foodborne Disease Surveillance and Drinking Water Hygiene (Food Letter (2014) No. 887).* http://www.nhfpc.gov.cn/sps/s5853/201410/1b44cd4be45441819f87f7a4f7e09523.shtml. Accessed March 27, 2015.

114 Li, Z., 2014, *Elementary school virus prevention week.* http://huodong.k618.cn/event/levy-15-view-1207534.html. Accessed March 27, 2015.

9

Food-borne Parasitic Diseases in China

Xue Bai[1]*, Xiaolei Liu*[1]*, Xiaonong Zhou*[2]*, Jiaxu Chen*[2]*, Xiuping Wu*[2]*,*
Pascal Boireau[3] *and Mingyuan Liu*[1]

[1] *Jilin University, Changchun, China*
[2] *Chinese Center for Disease Control and Prevention, Shanghai, China*
[3] *Animal Health Laboratory, Maisons-Alfort, France*

Food-borne parasitic diseases are human and animal diseases that are caused by helminths and protozoans, which are acquired through the consumption of infected or contaminated meat, fish, shellfish, molluscs, plants, water, reptiles, and amphibians. To date, 95 species of food-borne parasites have been identified; these parasites pose significant public health and socioeconomic problems [1]. The World Health Organization (WHO) focuses on food-borne parasitic diseases when conducting surveys to assess food-borne diseases. The organization has found that 7% of the world's food-borne diseases are caused by these parasites, which have become a major threat to human health and a public health problem. The infectious diseases caused by food-borne parasites are often referred to as neglected diseases, and from a food safety perspective, parasites have not received the same level of attention as other food-borne biological and chemical hazards. Nevertheless, they cause a high burden of disease in humans. The infections may have prolonged, severe, and sometimes fatal outcomes, resulting in considerable hardship in terms of food safety, security, quality of life, and negative impacts on livelihoods.

In 2014, Food and Agriculture Organization of the United Nations (FAO) and WHO composed a list of 24 parasites ranked according to their "importance" and their primary food vehicle. Meanwhile, the FAO/ WHO defined global criteria for evaluating the 24 food-borne parasites and rated each parasite according to these criteria: (a) number of global illnesses, (b) global distribution, (c) morbidity – acute, (d) morbidity – chronic, (e) percentage chronic, (f) mortality, (g) potential for increased burden, (h) trade relevance, and (i) socioeconomic impact. Finally, the top ten list was: *Taenia solium* (pork), *Echinococcus granulosus* (fresh produce), *Echinococcus multilocularis* (fresh produce), *Toxoplasma gondii* (meat from small ruminants, pork, beef, and game meat [red meat and organs]), *Cryptosporidium* spp. (fresh produce, fruit juice, and milk), *Entamoeba histolytica* (fresh produce), *Trichinella spiralis* (pork), *Opisthorchiidae* (freshwater fish), *Ascaris* spp. (fresh produce), and *Trypanosoma cruzi* (fruit juices).

Food Safety in China: Science, Technology, Management and Regulation, First Edition.
Edited by Joseph J. Jen and Junshi Chen.

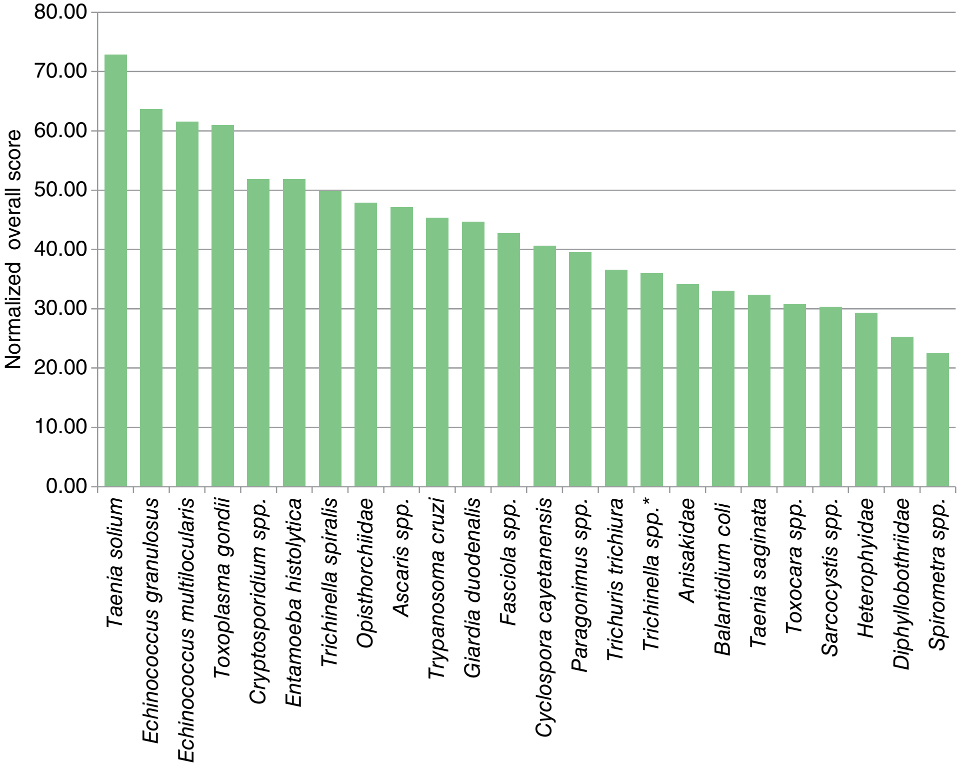


Figure 9.1 Global ranking of food-borne parasites using a multi-criteria ranking tool for scoring parasites and weighting of scoring criteria based on expert preference.

The results of the ranking exercise are presented in Figure 9.1, where the top-ranking parasites are arranged on the x-axis from top to bottom in decreasing rank order and the average weightings (in percentages) are arranged on the y-axis. This figure was obtained from the average of all elicited weightings for the criteria. Among the top-ranked parasites are those that have already been singled out by WHO as neglected tropical diseases (NTD) and identified by the WHO Food-borne Disease Epidemiology Reference Group (FERG) as priorities for further burden of illness studies [2].

Food-borne parasitic diseases are exhibiting new epidemiological characteristics in a society that is filled with economic development, ecological environmental changes, more frequent population flow, as well as diversities in dietary source and style. They have become a major risk factor for food safety and health care, and a global public health problem. In China, there are a variety of food-borne parasitic diseases, with a wide distribution, a high prevalence, and sudden outbreaks, which has resulted in a high burden of disease. This review will summarize information on the epidemic features, diagnosis, and technologies of food-borne parasitic diseases in China. Meanwhile, perspectives are given on the strategies for prevention of food-borne parasitic diseases, combined with foreign management and regulation.

9.1 Epidemic Features of Major Food-borne Parasitic Diseases in China

9.1.1 Various Food-borne Parasitic Diseases

The major food-borne parasites are divided into seven groups, including meat-borne, plant-borne, shellfish-borne, fish-borne, mollusc-borne, water-borne, and reptile- and amphibian-borne parasites. In China, approximately 20 species of food-borne parasitic diseases have been identified, including taeniasis/cysticercosis, trichinellosis, echinococcosis, sarcocystosis, and toxoplasmosis, which are caused by eating raw or undercooked meat (pork, lamb, beef, rabbit, and chicken), gnathostomiasis and diphyllobothriasis, which are caused by eating raw freshwater fish, such as finless eel and loach [3]. China has 56 ethnic groups with different ways of life and customs, and some people have a habit of consuming wild animals and raw meat [4,5]. Therefore, healthy eating habits have been recommended, and the consumption of wild animals is prohibited by legislation. In China, minority groups, such as people of Bai nationality, Dai nationality, and Hani nationality, continue the habit of eating raw or undercooked pork, especially on festival days. In addition, eating some characteristic snacks in the southwest of China, Yunnan Province and Fujian Province can easily lead to taeniasis suis.

Linguatuliasis was considered a rare parasitic disease, but some human diets have changed to include drinking fresh snake blood or eating snake gall and undercooked snakes; therefore, linguatuliasis is becoming increasingly common. When picking water chestnuts, people can easily become infected with fascioliasis, and when eating raw celery, with hepatic fascioliasis. *Cryptosporidium*, *Giardia* and *Cyclospora* are the main parasites causing watery diarrhoea [6]. *Cryptosporidium* is a global pollutant of surface water. Because of its resistance to the standard water chlorination method and its low infective dose (10 oocysts), *Cryptosporidium* can infect large numbers of people at the same time and is a potential biopathogen.

9.1.2 Food Safety Incidents Occur Frequently

Food-borne parasites can be transmitted by the ingestion of fresh or processed foods that have been contaminated with the transmission stages (spores, cysts, oocysts, ova, larval, and encysted stages) via the environment, animals (often from their faeces), or people (often due to inadequate hygiene). With globalization, food-borne parasitic infections are becoming more prevalent nationwide. Improved sanitation, health education, and the establishment of appropriate food safety mechanisms can assist in the control of many of these infections. However, food-borne parasitic infections are still common diseases in developed and developing regions, especially in rural China. Food-borne parasitic diseases cause death and serious diseases in humans and animals nationwide and are of public health significance and socioeconomic importance [7].

Trichinella spiralis has a unique lifecycle in which there is no environmental transmission stage. Thus, all cases are due to the ingestion of meat containing the encysted larvae; meat types typically associated with *T. spiralis* include pork, horse meat, and game. Globally, 65 818 human infections have been reported between 1986 and 2009; most of these were reported for hospitalized patients in Romania, where 42 patient deaths were reported. However, increased exposure may result from human behavioural trends, for example, the consumption of raw horse meat, dog meat, wild boar, and other sylvatic animal meats, as well as practices of free-range animal husbandry (infected animals are asymptomatic). Trichinosis is one of the three parasitic zoonoses in China (trichinosis, cysticercosis, and echinococciosis), but is also a consideration in importing and exporting meat quarantines. In recent years, trichinellosis cases have occurred in some regions of China. On 18 February 2009, an unknown disease broke out in Lanping County of Yunnan Province; nine people were seriously infected, and one person died, which caused public panic and national attention, before finally being diagnosed as trichinosis. In early 2013, trichinosis also broke out in Lancang County of Yunnan Province; 41 families had slaughtered swine within the previous two days, and among the villagers, 108 people had eaten the "raw chops". They presented with different degrees of fever, headache, diarrhoea, calf pain, body aches, facial edema, and other symptoms, finally being diagnosed as infected with *Trichinella*.

In 2006, several tourists ate *Pomacea canaliculata* ("fresh apple snails") in a Beijing restaurant. These tourists presented with fever, severe headache, neck rigidity, and body pain, finally being diagnosed with angiostrongyliasis. Residual *Angiostrongylus cantonensis* larvae were present due to processing problems with the snails.

In alveolar echinococcosis, the occurrence of alveolar echinococcosis in China accounts for more than 90% of the total global burden. The highest prevalence is in the Qinghai-Tibet plateau. Cases of echinococcosis from Xinjiang, Sichuan, Qinghai, Gansu, Ningxia, and Inner Mongolia account for 98.2% of the total number of cases reported in China. In Western China, 5783 cases were reported in 2008 in six provinces with a total population of 96 million people, resulting in an incidence of 6 cases per 100,000.

These frequent food safety incidents remind us to be careful of the food-borne parasite!

9.1.3 Number of Latent Infections is Increasing

From 2001 to 2004, a national survey of the prevalence of parasitic diseases was carried out in China (not including Taiwan, Hong Kong, and Macau), sponsored by the Ministry of Health, China, and involved stratified, random, and mass sampling. The data from that survey revealed two major trends in the epidemiology of parasitic diseases in China. First, the prevalence of intestinal parasites such as *Entamoeba histolytica*, *Fasciolopis buski* and soil-transmitted helminths has declined markedly in comparison to the rates recorded in the first national survey conducted in 1990 [8]. In 2003, the prevalence of hookworms, *Ascaris* and *Trichuris* had declined by 60.7%, 71.3% ,and 73.6%, respectively, and the number of people infected by soil-transmitted nematodes declined from 536 million in 1990 to 129 million in 2003; of these, 85.9, 39.3, and 29.1 million represent infections with *Ascaris lumbricoides*, *hookworms*, and *Trichuris trichiura*, respectively [9]. However, the infection rate with soil-transmitted helminths in China is still unacceptably high in comparison to economically developed countries such as Japan and South Korea.

Second, with regard to the prevalence of food-transmitted parasitic diseases, the fastest-growing food-borne parasitic diseases in China include clonorchiasis, angiostrongyliasis, echinococcosis, trichinellosis, and cysticercosis. The most striking example is clonorchiasis, for which the average national prevalence has increased by 75%

compared to the results of the first national survey, with an estimated 12.49 million people (0.58%) being infected in 2003 compared with 4.7 million (0.36%) in 1990. The prevalence of *Taenia* has increased by 52.49% nationwide, with Sichuan Province and the Tibet autonomous region having the highest increases of 98% and 97%, respectively [10].

9.1.4 Epidemic Areas are Expanding

Globalization is the spread and exchange of people, animals, goods, resources, ideas, and other physical or cultural materials. Globalization also facilitates the spread of infectious diseases, and this can have enormous negative consequences on food security, food safety, and food sovereignty, among which the spread of parasites, including food-borne parasites, ranks highly [11]. Some of these are related to lifestyle changes, including the consumption of raw or undercooked fish and meat, and curiosity about exotic foods and delicacies. An increasingly large transient population has also contributed.

Trichinellosis has become the most important food-borne parasitic zoonosis in China, having a high prevalence in domestic animals and humans. The first outbreak of human trichinellosis was documented in Tibet in 1964. Since then, more than 500 major outbreaks have been recorded in 12 of the 34 Chinese provinces, affecting 25 161 people and leading to 240 deaths. Most of the clinical (88.6%) and fatal (99.6%) cases occurred in southwestern areas (Yunnan, Guangxi and Tibet), where locals have the habit of eating raw pork meat [12].

Human angiostrongyliasis is caused by the larvae of the rat lungworm *Angiostrongylus cantonensis* and can cause eosinophilic meningitis. Humans become infected by ingesting freshwater and terrestrial snails and slugs. The first case of human angiostrongyliasis in mainland China was reported in 1984. Since then, approximately 400 human cases have been reported, including outbreaks of 65 cases in Wenzhou City of Zhejiang Province in 1997; 30 cases in Fuzhou, Fujian Province, in 2002; 28 cases in Yunnan Province between 2003 and 2005; and 131 cases in Beijing in 2006. Other sporadic cases have occurred in the Heilongjiang, Liaoning, Jiangsu, Zhejiang, Fujian, Guangdong, Yunnan, Beijing, and Tianjin provinces [13].

Echinococcosis, including cystic echinococcosis caused by the *Echinococcus granulosus* (*Cestoda; Taeniidae)* and alveolar echinococcosis caused by *Echinococcus multilocularis*, is regarded as one of the most serious parasitic zoonoses in China. A recent nationwide survey by the ELISA method estimated that approximately 380 000 people are infected with echinococcosis, and approximately 50 million are at risk of infection in China [10]. The endemic provinces are predominantly pastoral and semi-pastoral areas, including Inner Mongolia, Ningxia, Qinghai, Jilin, Henan, Sichuan, Guizhou, Yunnan, Shaanxi, Gansu, Tibet, and Xinjiang, but recently, Sichuan has become an endemic area of infection with echinococcosis. Genotyping hydatid cysts from humans and gravid tapeworms from dogs in Xinjiang in northwestern China revealed that the *E. granulosus* G1 genotype was the major source of this human cystic echinococcosis, although the G6 genotype was also present [14].

Clonorchiasis caused by the oriental liver fluke *Clonorchis sinensis* is considered one of the major parasitic zoonoses in some parts of China. Humans become infected with *C. sinensis* when they consume raw or undercooked freshwater fish and shrimp infected by *C. sinensis metacercariae*. A recent national survey showed that human clonorchiasis is endemic in 27 provinces (including municipal cities and autonomous regions). The Guangdong Province has the largest number of infected people (approximately 5.5 million) because of the habit of local people of eating raw and undercooked fish [15].

Cryptosporidiosis is one of the emerging parasitic zoonoses in China and is considered by the WHO Neglected Diseases Initiative as an important infectious disease. In the United States, an estimated 8% of the annual food-borne disease burden may be attributed to this parasite. In 1987, the first case of cryptosporidiosis was identified in the city of Nanjing, China. Subsequently, many cases were reported from more than ten provinces. The prevalence of cryptosporidiosis in diarrhoea patients ranged between 1.4% and 13.3% and was most commonly found in children [16]. A recent survey of cryptosporidiosis revealed a prevalence of 3% in children with diarrhoea, and children of one to four years old had the highest prevalence at 5.5%.

9.1.5 Intermediate Hosts are Widespread, and Infection Rates Remain High

Food-borne parasites have a wide range of hosts, whether definitive hosts or intermediate hosts, including mammals, birds, fish, and other animals.

To date, *Trichinella* has been found in 14 species of animals, including the pig, dog, cat, rat, cow, fox, bear, tiger, marten, raccoon, elk, wolf, and wild boar, and is distributed in all Chinese provinces except the Hainan and Taiwan islands [17]. Swine trichinellosis is a serious problem in China because the prevalence is high in some provinces. Among them, Hubei is the most affected province, with a prevalence of 6.76% by direct diagnostic methods (microscopy or artificial digestion) in the slaughterhouses. In Henan Province, the average prevalence was up to 4.27% by direct detection methods in 43 counties, and in some counties, the level remained extremely high (e.g., reaching 50.4% and 36.1% in Xinye and Deng counties, respectively). Dogs are also prevalently infected in northeastern China. The trichinellosis prevalence in dogs is as follows: 9.82% in Jilin Province, 39.5–44.8% in Heilongjiang Province, 23.52% in Inner Mongolia, and 35.6% in Liaoning Province.

In China, approximately 140 species of freshwater fish and four species of shrimp have been recognized as second intermediate hosts for *C. sinensis*. The prevalence of infected fish is still high in some provinces. Cats and dogs are the most important animal reservoirs for human infection and show high prevalence in some provinces [18].

Anisakiasis has become an important food-borne zoonotic parasitic disease and is ranked as a second-class dangerous parasitic disease in entry-exit inspection and quarantine in China. In the first case of human anisakiasis in China, the patient, a 56-year-old male citizen of Dalian, was admitted to hospital with vomiting, peripheral umbilicus and abdominal distension, and frequent mucous diarrhoea. The patient was examined using an electronic gastroscope, which displayed a parasite residing in the stomach, and subsequently, gastroscope-assisted surgery was implemented. By the end of 2011, 194 of the 239 species of fish inspected were found to be infected with *Anisakis* in China; the infection rate was 81.17%. Of 6969 fish tails checked, 2722 tails were infected, and the infection rate was 39.06%. For the 32 species of fish checked, the infection rate was 100% [19].

9.1.6 Great Economic Losses

Food-borne parasites not only lead to enormous economic losses in animal husbandry, the meat industry, agribusiness, and trade, but also pose a severe threat to public health. Diseases caused by *Taenia solium* (ranked 1st in Figure 9.1) and *Echinococcus granulosus* and *E. multilocularis* (ranked 2nd and 3rd in Figure 9.1, respectively) contribute to economic losses in human and animal populations in many parts of the world. If the parasites are ranked only on trade criterion scores, the order of importance changes: *Trichinella spiralis, Taenia solium, Taenia saginata, Anisakidae* and *Cyclospora cayetanensis* are the top five. Infections from these parasites are considered preventable diseases that can be controlled or eliminated and should be prioritized [20].

Taeniasis and cysticercosis are widespread food-borne disease infections with adult and larval *Taenia*, respectively. Nationwide, 550 000 people have been estimated to be infected. The treatment of taeniasis costs 3918.93 CNY/person; treatment for 550 000 people would cost 31.3 billion yuan. Each year, 200 million kilograms of pork are infected by *cysticercus* in China, and the direct economic loss amounts to $121 million [21].

Echinococcus granulosus and *E. multilocularis* represent a substantial burden on the human population. Present estimates suggest that cystic hydatid disease, caused by *E. granulosus*, results in the loss of 1–3 million disability-adjusted life years per annum. The annual cost of treating cases and the economic losses to the livestock industry probably amount to $2 billion USD. Alveolar echinococcosis, which is caused by *E. multilocularis*, results in the loss of approximately 650,000 disability-adjusted life years per year. These diseases are perhaps some of the more important global parasitic diseases, with more than 1 million people affected at any one time, many showing severe clinical syndromes [22]. In China, alveolar echinococcosis (AE) was "The Second Cancer in Tibet". The Tibetans do not harm wild dogs and feed them for religious reasons, resulting in freely roaming wild dogs. People become infected with *E. multilocularis* due to contact with the wild dogs [23]. Treatment of a case of hydatid disease costs as much as 2700–8000 CNY/person, which causes great difficulty to local residents and huge economic losses. Meanwhile, animal infections with alveolar echinococcosis cause the loss of approximately 8 million yuan in animal by-products per year in China.

For *Trichinella* (ranked 7th in Figure 9.1), the cost of inspection of food, and prevention and control of food-borne parasites remains high. The cost of inspection for *Trichinella* is approximately 2.2 billion CNY per year in China, 0.62 billion EUR per year in the European Union, and 1.2 billion USD per year in the United States.

More than 700 million domestic animals are at risk worldwide, and economic losses exceed 2 billion USD per year because of fascioliasis.

9.1.7 Severe Threats to Human Health

Infections from food-borne parasites such as *Taenia solium* and *Trichinella* spp. can lead to severe clinical syndromes and are potentially fatal. Some food-borne parasites can infect humans chronically and can even have carcinogenic potential, such as observed with *Opisthorchiidae* and *Cryptosporidium* spp.

The main clinical symptom of human trichinellosis is the muscular phase, which is accompanied by diarrhoea, edema, fever, facial swelling, heavy muscle pains, conjunctivitis, and splinter haemorrhages [24]. Death is now rare, owing to improved treatment, but may result from congestive heart failure due to myocarditis, encephalitis, pneumonitis, hypokalaemia, or adrenal gland insufficiency [25].

Taenia solium is estimated to infect millions of people worldwide. This parasite is unique in that the larval or cysticercus stage can infect humans as well as pigs, and can cause a wide range of debilitating neurological problems, including the potentially lethal neurocysticercosis (NCC), ocular cysticercosis (OCC), and subcutaneous cysticercosis (SCC). The disease can be spread by poor sanitation, poor hygiene, and improper slaughterhouse services. Human neurocysticercosis is increasingly being reported in developed countries, possibly due to increases in globalization and immigration [26].

Approximately 30% of the world population has been estimated to be infected by *Toxoplasma gondi* (ranked 4th in Figure 9.1), and although the majority of infections are asymptomatic, serious complications can occur during pregnancy and in the immunocompromised. Severe toxoplasmosis, causing damage to the brain, eyes, or other organs, can develop from an acute *Toxoplasma* infection [27]. Most infants who are infected while still in the womb have no symptoms at birth, but they may develop symptoms later in life. A small percentage of infected newborns have serious eye or brain damage at birth [28]. Furthermore, the importance of this parasite may increase should chronic conditions, including chronic mental sequelae, be found in association with the infection.

The importance of *Cryptosporidium* spp. (ranked 5th in Figure 9.1) as a food-borne parasite has emerged in part through outbreak investigations that have linked fresh produce, fruit juice, and dairy products to the disease. For most people, symptomatic cryptosporidiosis is characterized by acute watery diarrhoea, often accompanied by abdominal pain, nausea and/or vomiting, low-grade fever, headache, and general malaise. Most patients recover within two to three weeks, but highly immunocompromised patients may suffer chronic illness, leading to severe disease and sometimes death. For most parasitic infections, some treatment is available, but for *Cryptosporidium* spp. infections in the immunocompromised, none is available. Increasing evidence shows that cryptosporidiosis may have long-term effects, such as chronic gastrointestinal conditions. In addition, cryptosporidium oocysts are very resistant to the chlorine commonly used to treat water.

Giardiasis is the most frequently diagnosed intestinal parasitic disease in China and among travellers with chronic diarrhoea. Signs and symptoms may vary and can last for one to two weeks or longer. In some cases, people infected with *Giardia* have no symptoms. Acute symptoms include diarrhoea, gas, greasy stools that tend to float, stomach or abdominal cramps, upset stomach or nausea/vomiting, and dehydration (loss of fluids) [29].

Human anisakiasis is caused by larvae of some genera of the family Anisakidae. The signs and symptoms of anisakiasis are abdominal pain, nausea, vomiting, abdominal distention, diarrhoea, blood and mucus in the stool, mild fever, allergic reactions with rash and itching, and infrequently, anaphylaxis [30].

9.2 Diagnostic Technologies for Food-borne Parasitic Diseases in China

Food-borne parasitic diseases have become one of the important factors affecting public health and food safety. At present, diagnostic methods for food-borne parasites rely on the use of morphological identification and remain highly dependent on light or electron microscopy, which can provide a useful confirmation of clinical infection, and can also be used in surveys of food-borne parasites in endemic regions. However, microscopy lacks sensitivity, is labour intensive, and requires well-trained microscopists for accurate identification and interpretation, particularly for parasites that are morphologically similar, very small in size, or present in very low numbers [31]. Therefore, a rapid, highly sensitive, and specific diagnosis method is a trend in the development of food-borne parasite diagnostics. Modern molecular and immunological techniques have been developed in China and abroad, but the standardization and application of these techniques in inspections and quarantines need to proceed more rapidly. This part describes some of the methods and standards that were previously used and some that are currently used to detect parasites in food.

9.2.1 Chinese Standards

Currently, for the detection of food-borne parasites, four national standards exist: the inspection for parasites in food for import and export (SN/T 1748-2006), standard examination methods for drinking water – microbiological parameters (GB/T 5750.12-2006), protocol for the isolation and identification for parasite eggs or oocysts from kimchi and other plant foods (SN/T 1908-2007), and a protocol for quarantine techniques for parasites in freshwater fish (SN/T 25003-2010).

9.2.2 Morphological Identification

In China, according to the different food sources, different quarantine items and methods exist to test for food-borne parasites in imported and exported foods:

1) Direct microscope examination methods are mainly used for fast detection of larvae and cysticercus of *Trichinella spiralis* in meat and fish. Under a trichinoscope, larvae will appear coiled within an individual muscle cell, and the muscle cell typically appears oval in shape as a result of the formation of the capsule.
2) Artificial digestion is used in the inspection of meat for *Trichinella spiralis*, and the international testing method for *Clonorchis sinensis* in fish still uses pressing microscopy and the pepsin digestion method.
3) The candlelight method is used for testing for metacercariae, *Gnathostoma* cysts, *Angiostrongylus,* and *Diphyllobothrium plerocercoids* in fish.
4) The extrusion and candle method is used to test for metacercariae in the meat of translucent fish.
5) The mechanical separation method is used for testing for metacercariae, *Gnathostoma* cysts, *Angiostrongylus larvae,* and *Diphyllobothrium plerocercoids* in fish.
6) The concentration method is used for testing for the eggs of *Ascaris* and *Trichuris trichiura* on fresh vegetables.

9.2.3 Immunoassays

Immunoassays have the benefits of technical simplicity, rapidity, and cost effectiveness. In recent years, latex particle agglutination tests, co-agglutination tests, colloidal gold immune chromatography (GICA), enzyme-linked immunoassays (ELISA), and direct immunofluorescence antibody assays have been available for use in food-borne parasite inspections. However, immunodiagnostic assays commonly are hampered by antigenic cross-reactivity (among related or distinct taxa) and low specificity and often do not allow for distinction among current infection, past infection, and/or exposure [32, 33]. Recently, some rapid assay kits have been shown to exhibit low sensitivity in detecting the full range of parasites within a genus [34].

A type of chromatography card to test trichinosis (pork TS card) has been developed, which is specific, sensitive and rapid (3–12 min), suitable for detecting the blood of pigs, dried blood, serum, and tissue fluid, and can be used for screening *Trichinella* infection in pork or for monitoring sites [35]. Thiruppathiraja used anti-oocyst antibody and alkaline phosphatase double gold particles to establish a rapid immune-dot blot probe (IDBA) technology; the detection of *Cryptosporidium* in the water and environment shows a minimum detection of 10 oocysts/ml, which is 500 times the sensitivity of conventional methods [36]. A competitive enzyme-linked immunosorbent assay using the rabbit polyclonal antibody has also been developed; it can detect the larvae of *Anisakis* in seafood, and the lowest detection limit is approximately 5/1 kg [37].

9.2.4 Molecular Biology Detection

The advent of molecular tools, particularly those based on the polymerase chain reaction (PCR), resulted mainly in common PCR, multiplex PCR, PCR-ELISA, nested PCR, real-time PCR, and gene chip, which have provided a major advance for the food industry because of the ability to detect low levels of pathogens on food [31, 38].

9.2.4.1 Polymerase Chain Reaction (PCR)

A single PCR test for the simple and unequivocal differentiation of all currently recognized genotypes of *Trichinella* has been developed. The technique was developed further to distinguish genotypes at the level of single muscle larvae using a nested, multiplex PCR. In this PCR, the entire internal transcribed spacer region, as well as the gap region of the expansion segment V of the large subunit ribosomal DNA, is amplified concurrently in a first-round PCR using primer sets specific for each region, followed by the multiplex PCR for final diagnosis [39]. Multiplex PCR utilizes more than one set of primers in a reaction and has been used for the simultaneous detection of multiple pathogens in one sample [40, 41]. However, limitations of PCR include inhibitors in the foods, which can result in false positives. Food-derived PCR inhibitors include Ca^{2+}, fats, glycogen, and phenolic compounds [42]. The presence of proteases in cheese and milk may also inhibit PCR [43, 44], and the detection of *Cryptosporidium* in water and food samples is often hampered by the occurrence of organic and inorganic substances that can potentially be PCR inhibitors [45]. PCR-ELISA allows the fast and non-radioactive detection of PCR products on the microplate. Kellogg used PCR-ELISA to detect *Toxoplasma* contamination in water [46]. This method can provide positive, confirmed results in less than a day. Fewer than 50 oocysts can be detected following recovery of oocyst DNA. The development of a PCR detection method to detect the *T. gondii* oocyst will provide a useful technique to estimate levels present in surface waters.

9.2.4.2 Quantitative PCR (qPCR)

The invention of quantitative PCR (qPCR) has overcome several limitations of conventional PCR and led the way to rapid enumeration of food-borne pathogens [33, 34]. In qPCR, the amplified product is detected using fluorescent dyes. These fluorescent dyes are linked to oligonucleotide probes, which bind specifically to the amplified PCR product. This not only allows highly sensitive and specific detection of the target sequences, but also enables very accurate quantitation of the target sequence [34, 47]. One study evaluated whether freshwater bivalves can be used to detect the presence of *Toxoplasma gondii* in water bodies. The presence of *T. gondii* was investigated in mussel tissues by qPCR [48]. By using real-time fluorescence quantitative PCR, the detection limit for *Trichinella spiralis* is approximately 0.01 larvae/1 g of tissue homogenate [49]; for *Anisakis*, 1 mg body tissues/25 g fish samples [50]; and for *Cryptosporidium* oocysts in water samples, < 10 oocysts [51]. This PCR is a reliable, specific, and sensitive detection method.

9.2.4.3 Loop-Mediated Isothermal Amplification (LAMP)

LAMP employs four primers that have a total of six binding sites on the target DNA. It uses a robust polymerase (BST) to amplify the target DNA (or RNA by inclusion of reverse transcriptase) proceeding to an autocycling strand displacement mechanism while at a constant temperature and producing detectable product in approximately 1 h [52]. The procedure is robust, rapid, and able to amplify from a single copy to 10^9 in 1 h at constant temperature, typically in the range of 60–70°C [52, 53]. LAMP can also be applied to nucleic acid extracts of unpurified samples or even to samples without nucleic acid extraction, which demonstrates its general insensitivity to extraneous materials other than the target; that is, *Toxoplasma* oocyst DNA have been detected efficiently in crude faecal nucleic acid extracts [53]. A rapid, sensitive, and specific method for detecting the food-borne trematode *Opisthorchis viverrini* from stool samples using LAMP was developed to obtain results within 40 min, using a heat box or a water bath to maintain the temperature at 65 °C [54]. LAMP assays have also been developed for the detection of *Cryptosporidium* and *Giardia* in water and faeces.

Different PCR methods that have two major advantages have been developed in the past few years [18, 55, 56]. First, PCR shows high performance in the diagnosis of low-intensity infection. Second, the technique allows *C. sinensis* to be distinguished from other trematode species. The LAMP technique has been developed to detect *C. sinensis* infection in intermediate hosts [57, 58]. Studies to diagnose human *C. sinensis* infection with LAMP are warranted in view of the simplicity of this technology compared with PCR.

9.2.4.4 DNA Chips

A DNA chip (also commonly known as a DNA microarray or biochip) is a collection of microscopic DNA spots attached to a solid surface. Scientists use DNA microarrays to measure the expression levels of a large number of genes simultaneously or to genotype multiple regions of a genome. Each DNA spot contains picomoles (10^{-12} moles) of specific DNA sequences, known as a probes (or reporters or oligos). These can be a short section of a gene or another DNA element, used to hybridize a cDNA or cRNA (also called anti-sense RNA) sample (called a target) under high-stringency conditions. Probe-target hybridization is usually detected and quantified by the detection of fluorophore-, silver-, or chemiluminescence-labeled targets to determine the relative abundance of the nucleic acid sequences in the target.

Wang and colleagues designed oligonucleotide chips with specific probes based on genera, species, and sub-species. This chip, combined with multiple PCR, successfully identified *Entamoeba histolytica Schaudinn*, *Giardia lamblia*, and *Cryptosporidium parvum* [59]. Brinkman researched and developed DNA chip technology to detect five types of pathogenic microorganisms in natural water, such as *C. parvum* and *C. tyzzeri*, to facilitate the timely assessment of the risk of exposure to water-borne pathogens [60].

9.3 Management and Regulation of Food-borne Parasitic Diseases in China

Internationally, the incidence rate of parasitic diseases is thought to be a major marker to measure the level of civilization and social development of a country. World trade, climate change, and population movement are important indicators challenging the management of parasitic diseases. At present, in China, the outlook on the prevalence and diagnosis of parasitic diseases is not optimistic. Management and regulation of food-borne parasitic diseases have become difficult because of lagging diagnostic technology, the lack of professional personnel, and an imperfect food safety control system. Since mid-December 2011, a series of persons complaining of fever and hepatalgia were admitted to local hospitals in Yunnan Province. The patients were suspected to be infected by *Fasciola gigantica*. This incident also shows that the prevention and control of rare parasitic diseases is still neglected [61].

In the face of new situations, new problems and the complexity of food-borne parasitic diseases, we should investigate and determine the epidemic status of food-borne parasitic diseases in China, actively work to improve the level of diagnosis and treatment of food-borne parasitic diseases, and strengthen prevention and control efforts. Furthermore, to control emerging and re-emerging parasitic diseases, techniques for detection, surveillance and infection source-tracking must be further improved.

9.3.1 Formulation of Laws and Regulations

The development and implementation of a series of laws and regulations for the prevention and control of infectious diseases in humans, domestic animals, and wild animals is in progress. These laws and regulations will define the responsibilities of governments at all levels and will help them report, control, treat, and take other emergency measures against food-borne parasitic diseases in humans, domestic animals, and wild animals [62].

At present, the inspection and quarantine of food-borne parasites in China is improving gradually. For water, the "Water quality standards for urban water supply (CJ/T206-2005)" and "Standards for drinking water quality (GB5749-2006)", which were published in China in 2006, added two non-routine procedures for the identification of *Giardia* and *Cryptosporidium*, and proposed the immunomagnetic separation of fluorescent antibody method as a corresponding detection method; this method provides the conventional indicators, with the limit value for *Cryptosporidium* (per 10 l is the optimum) < 1 and for *Giardia lamblia* (per 10 l is the optimum) < 1.

In China, food safety law stipulates that food must not contain pathogenic microorganisms and parasites, and the meat hygiene inspection trial procedures jointly issued by different ministries (health, agriculture, and foreign trade) and the ministry of commerce stipulate those parasites in the meat after slaughter that require quarantine, which include *Trichinella spiralis, cysticercus* and *sarcocys*tis [7]. The inspection method for

Trichinella spiralis and *sarcocystis* is diaphragm tableting microscopy. Examination of *cysticercus* is mainly from visual observation of incisions of masseter muscle, waist deep muscle, and the diaphragm, to allow viewing of any rice-like, grey, transparent cysticercus packages. However, the detection rate of these methods is high, and segmenting of the meat is not suitable. Therefore, health departments and food supervision departments need to revise and supplement the current standards and regulations to clarify the types and stages of parasite infection and to facilitate practical operation and application.

Meat inspection for trichinellosis and cysticercosis is required in European Union countries, as described under Regulation 854/2004 for pigs and cattle at slaughter and in six other export countries, including Australia, Canada, Japan, New Zealand, Norway, and the United States [31].

9.3.2 Establishment of the Disease Reporting and Surveillance Systems

The complexities connected to the epidemiology and life cycle of each parasite play a central role in identification, prevention, and control of the risks associated with food-borne parasitic diseases. Surveillance for parasitic diseases is complicated by the often prolonged incubation periods, sub-clinical nature and unrecognized, chronic sequelae. The established disease-reporting systems for humans, domestic animals, and wild animals are used to collect, collate, and analyze the epidemiological information on animal epidemic diseases and are responsible for monitoring the diagnosis of animal diseases. Using the present reporting system, hospitals and clinics can immediately and directly report cases through the internet, allowing public health officials to have information on diseases, which provide the foundation for the design and implementation of control strategies and measures [63].

The United States has many participants in its food-borne disease-monitoring system. In 2011, the US Centers for Disease Control (CDC) list of nationally notifiable infectious conditions contained only four water-borne and food-borne parasites: *Cryptosporidium*, *Cyclospora*, *Giardia*, and *Trichinella* [64]. Most CDC monitoring system data come from public health agencies in various states or regions. In the United States, agencies responsible for safe drinking water, produce, seafood, and meat include the US Environmental Protection Agency (USEPA), the Food and Drug Administration (FDA), the US Department of Commerce's (USDC) National Oceanic and Atmospheric Administration (NOAA), and the US Department of Agriculture (USDA) [31].

After World War II, more than 70% of Japanese people were infected with intestinal parasites, and that situation was similar to the situation in some developing countries today. However, after 30 years, Japan had eliminated the main food-borne parasitic disease because parasite-control programmes were introduced that were devised and conducted by parasitologists. Meanwhile, the Tokyo Public Hygiene Association (TPHA) and the Japan Association of Parasite Control (JAPC) were formed, and school-health-based parasite control was initiated nationwide [65]. These measures effectively controlled parasite epidemics.

9.3.3 Establishment of the International and National Veterinary Reference Laboratories or Collaboration Centres

Establishment of a reference laboratory was needed for important food-borne parasitic diseases, allowing studies in basic research and the application of epidemic prevention.

This laboratory was needed to promote the study of the technology of diagnosis, prevention, control, and eradication of animal diseases, and development of a final strategy [66]. The European Union set up reference laboratories, which are responsible for training and final confirmation of suspected samples; work labs are responsible for the testing of samples. With the improvement of veterinary science and technology, an increasing number of reference laboratories have been established. In May 2015, in China, The World Organisation for Animal Health (OIE) collaborated to establish a centre for food-borne parasites in the Asian-Pacific region in the Institute of Zoonoses of Jilin University to provide more comprehensive monitoring and detection of food-borne parasitic diseases. By the end of 2015, the OIE had set up a total of 12 reference laboratories and three collaborating centres in China.

9.3.4 Implementation of Special Projects and Increasing the Investment in Important Food-borne Parasites

A special project for the prevention and control of important food-borne parasites has been conducted with an increase in the financial support from central and local governments. The aims of this project were to reduce incidence of and mortality from food-borne parasitic diseases and to improve governmental emergency response and capabilities of disease prevention and control. The project has also focused on the detection of food-borne diseases and laboratory monitoring with standardized technology, providing technical support for emergency decisions related to food-borne diseases.

In the 1960s and 1970s, eradication of snails was considered the focal point of the schistosomiasis control campaign, despite concerns that the molluscicides might lead to environmental pollution. Since the 1980s, the use of praziquantel for mass chemotherapy has become the chief means to control schistosomiasis. In 2004, the State Council established two targets for the National Schistosomiasis Control Program. In 2007, the Chinese Central Government demonstrated its commitment to enhance fundamental research into the food-borne diseases problem by funding a project for basic research relating to the control of schistosomiasis and malaria through the National Basic Research Program of China (i.e., the 973 program). This strengthened the national control program and, when implemented, effectively reduced schistosomiasis infections [67, 68].

In addition, insufficient financial support for research on and control of food-borne parasitic disease from central and local governments has resulted in an increase in the proportion of food-borne parasite infection. For example, when the World Bank Loan Project ended in 2001, a corresponding drop occurred in the funding for schistosomiasis control, which in turn caused an increase in human cases of schistosomiasis in 2003 [7, 69].

9.3.5 Development of a Food-borne Parasitic Disease Vaccine and New Drugs

The research and development of new drugs is an effective way to control the drug resistance of the parasite. Many of the new drug targets are being discovered with much more ease as the genomic sequences of many parasitic organisms are becoming available. A pressing need exists for the identification of compounds that are efficacious in *in vivo* animal studies and can be subjected to clinical trials.

Drug development for *C. parvum* is particularly challenging because of the difficulty of *in vitro* screening. Maximum effort should be directed towards new compounds to treat cryptosporidiosis because of the limited availability of effective drugs [70].

9.3.6 Surveillance of Exotic Diseases

The spread of food-borne parasitic diseases is enhanced by changes in human behaviour, demographics, environment, climate, land use, and trade, among other drivers [71]. Most emerging and re-emerging zoonotic diseases come from wildlife. The globalization of food trade offers new opportunities for dissemination and variations in food preferences and consumption patterns. For example, meat consumption in emerging countries is expected to increase globally over the next 20 years because of the rising tendency to eat meat, fish, or seafood that is raw, undercooked, smoked, pickled or dried, or the demand for exotic foods, such as bush meat or wild game. In China, a large number of wild animals are imported from Africa, South America, Oceania, and other sources every year. To prevent certain exotic diseases that are emerging abroad, the government seeks to strengthen the surveillance and control of cross-border transmission of exotic diseases and has established the Joint Control Mechanism of Transboundary Food-borne Parasitic Diseases [72]. Because of increasing international communication, food-borne parasitic infections are becoming more prevalent nationwide. Not only is the number of immigrants infected increasing, but infectious vectors are also entering the region. Therefore, we should strengthen the detection of immigrants. Increasing safety management and supervision in the food industry and strengthening the control of raw food materials are the most effective ways to reduce the occurrence of food-borne parasitic diseases.

9.3.7 Emphasis on Interdisciplinary and International Cooperation

Interdisciplinary and cross-sector collaborations, with communication occurring among human, animal, and environmental health services, reflect the “One Health” strategy to confront emerging food-borne parasitic disease. One Health is a collaborative effort between multiple disciplines working locally, nationally, and globally to attain optimal health for people, animals, and the environment. Moreover, an emphasis should be placed on the construction of international early warning systems through international collaboration and coordination to detect unknown infectious diseases of international public health importance [73].

Enhancement of collaboration among the World Health Organization, the Food and Agriculture Organization of the United Nations (FAO), the Office International Des Epizooties, and the World Bank is needed. For example, the FAO has established a global network of professionals directly involved in food-borne zoonotic diseases, including cysticercosis and echinococcosis, and this network provides a basic framework for the spread of information related to the diagnosis, prevention, and control of major zoonotic diseases [74]. Significant progress has been made in international cooperation on the control of schistosomiasis, cysticercosis, and echinococcosis in China [69, 75].

9.3.8 Health Education

Education and increasing awareness were identified as important components of food-borne parasite control and, in some cases, may be the only feasible options available. Education should be directed at participants throughout the food chain, from farm and abattoir workers to food handlers (consumers and food retail outlets), and should address good animal husbandry practices, and hygiene and sanitation measures. In terms of consumer education, a need may exist to address specific high-risk population groups. For consumers, especially those who are pregnant or immunocompromised (e.g., individuals with HIV/AIDS), advice on the preparation and consumption of high-risk foods, such as fresh produce and tubers, carrots, and so on, adequate cooking of meat and fish prior to consumption, and the importance of hygiene, for example, handwashing, is critical. Pets may be another important source of zoonotic diseases in China, including rabies and toxoplasmosis. The proper care of pets may prevent the transmission of pet-borne zoonotic diseases to humans; care would include the compulsory vaccination of pets, keeping pet living areas clean, and washing hands thoroughly after handling pets [76].

Educational campaigns utilize various media, in particular TV and radio, to promote awareness of the significance of and control strategies for food-borne parasitic diseases. The change of people's unhealthy eating habits is crucial to the successful control of food-borne parasitic diseases in some parts of China, particularly for some ethnic groups [7]. Popularizing health knowledge, striving to improve people's self-protection awareness, gradually changing irrational cooking and eating habits, and controlling the sources of infection, are conducive to the protection of vulnerable populations.

In conclusion, at present, research progress on food-borne parasitic diseases has many disadvantages in China, which shows a large gap with developed countries. We should actively learn from the experiences of the developed countries to improve the prevention and control programs of food-borne parasitic diseases.

References

1 LiHua, X., Ryan, U., YaoYu, F.(2015) *Biology of Foodborne Parasites*, CRC Press, Taylor&Francis Group.

2 Food and Agriculture Organization of the United Nations and World Health Organization. (2012) *Multicriteria-based ranking for risk management of food-borne parasites. Microbiological Risk Assessment Series No. 23*. Report of a Joint FAO/WHO Expert Meeting, September 3–7, 2012, Rome, Italy.

3 Zengshan, L. (2007) *Food Pathogenic Microbiology*, China Light Industry Press. [In Chinese].

4 Kruse, H., Kirkemo, A.M., Handeland, K. (2004) Wildlife as source of zoonotic infections. *Emerging Infectious Diseases*, 10, 2067–2072.

5 Li, T., He, S., Zhao, H. *et al.* (2010) Major trends in human parasitic diseases in China. *Trends in Parasitology*, 26(5), 264–270.

6 Rose, J. B., Slifko, T. R. (1999) *Giardia*, *Cryptosporidium*, and *Cyclospora* and their impact on foods: A review. *Journal of Food Protection*, 62(9), 1059–1070.

7 Zhou, P., Chen, N., Zhang, R.L. *et al.* (2008) Food-borne parasitic zoonoses in China: perspective for control. *Trends in Parasitology*, 24(4), 190–196.

8 Xu, L.Q., Yu, S.H., Jiang, Z. X. *et al.* (1995) Soil-transmitted helminthiases: nationwide survey in China. *Bulletin of the World Health Organization*, 73(4), 507–513.

9 YingDan, C., LinHua, T., LongQi, X.(2008) Current status of soil-transmitted nematode infection in China. *Biomedical and Environmental Sciences*, 21(2), 173–179.

10 Coordinating Office of the National Survey on the Important Human Parasitic Diseases. (2005) A national survey on current status of the important parasitic diseases in human

population. *Chinese Journal of Parasitology and Parasitic Diseases.* 23(5 Suppl), 332. [In Chinese].

11 Robertson, L. J., Sprong, H., Ortega, Y. R. *et al.*(2014) Impacts of globalisation on foodborne parasites. *Trends in Parasitology*, 30(1), 37–52.

12 Liu, M., Boireau, P.(2002) Trichinellosis in China: epidemiology and control. *Trends in Parasitology*, 18(12), 553–556.

13 Lin, W., Wang, X. (2004) Epidemiology of *Angiostrongylus cantonensis* in mainland. *Chinese Journal of Zoonoses*, 20(11), 1004–1007. [In Chinese].

14 Bart, J., Abdukader, M., Zhang, Y. *et al.* (2006) Genotyping of human cystic echinococcosis in Xinjiang, PR China. *Parasitology*, 133(5), 571–579.

15 Lun, Z.-R., Gasser, R. B., Lai, D.H. *et al.* (2005) Clonorchiasis: a key foodborne zoonosis in China. *The Lancet Infectious Diseases*, 5(1), 31–41.

16 Yang, X. (2005) Epidemic characteristics of human cryptosporidiosis. *Parasitic Disease and Infectious Disease*, 3(3), 135–137. [In Chinese].

17 Wang, Z., Cui, J. (2001) The epidemiology of human trichinellosis in China during 1964-1999. *Parasite*, 8, S63–S66.

18 Tang, J., Lin, R., Zhu, X. (2007) Clonorchis sinensis infection in animals in China. *Chinese Journal of Zoonoses*, 23(2), 177–179. [In Chinese].

19 Tang, Y., Sun,Q., Peng, P. *et al.* (2012) Research advances of Anisakiasis in China. *Journal of Anhui Agricultural Sciences*, 40(24), 12079–12081. [In Chinese].

20 Carabin, H., Budke, C. M., Cowan, L. D. *et al.* (2005) Methods for assessing the burden of parasitic zoonoses: echinococcosis and cysticercosis. *Trends in Parasitology*, 21(7), 327–333.

21 Wu, W., Qian, X., Huang, Y. *et al.* (2012) A review of the control of clonorchiasis sinensis and Taenia solium taeniasis/cysticercosis in China. *Parasitology Research*, 111(5), 1879–1884.

22 World Health Organization.(2011) *Report of the WHO informal working group on cystic and alveolar echninococcosis surveillance, prevention and control, with the participation of the Food and Agriculture Organization of the United Nations and the World Organisation for Animal Health*, 22–23 June 2011, Department of Control of Neglected Tropical Diseases, WHO, Geneva, Switzerland.

23 Xia, D., Yan, L.N., Li, B. *et al.* (2005) Orthotopic liver transplantation for incurable alveolar echinococcosis: report of five cases from west China. *Transplantation Proceedings,* 37(5), 2181–2184.

24 Capo, V., Despommier, D. D.(1996) Clinical aspects of infection with *Trichinella* spp. *Clinical Microbiology Reviews*, 9(1), 47–54.

25 Bruschi, F., Murrell, K.(2002) New aspects of human trichinellosis: the impact of new Trichinella species. *Postgraduate Medical Journal*, 78(915), 15–22.

26 Carabin, H., Ndimubanzi, P. C., Budke, C. M. *et al.* (2011) Clinical manifestations associated with neurocysticercosis: a systematic review. *PLoS Neglected Tropical Diseases*, 5(5), 1–13.

27 Hill, D., Dubey, J.(2002) Toxoplasma gondii: transmission, diagnosis and prevention. *Clinical Microbiology and Infection*, 8(10), 634–640.

28 Olariu, T. R., Remington, J. S., McLeod, R. *et al.* (2011) Severe congenital toxoplasmosis in the United States: clinical and serologic findings in untreated infants. *Pediatric Infectious Disease Journal*, 30(12), 1056–1061.

29 Feng, Y., Xiao, L. (2011) Zoonotic potential and molecular epidemiology of Giardia species and giardiasis. *Clinical Microbiology Reviews*, 24(1), 110–140.

30 Audicana, M. T., Kennedy, M. W. (2008) *Anisakis simplex*: from obscure infectious worm to inducer of immune hypersensitivity. *Clinical Microbiology Reviews*, 21(2), 360–379.

31 McCarthy, J. S., Lustigman, S., Yang, G.J. *et al.* (2012) A research agenda for helminth diseases of humans: diagnostics for control and elimination programmes. *PLoS Neglected Tropical Diseases*, 6(4), e1601.

32 Huang, S.Y., Zhao, G.-H., Fu, B.Q. *et al.* (2012) Genomics and molecular genetics of *Clonorchis sinensis*: Current status and perspectives. *Parasitology International*, 61(1), 71–76.

33 Gorski, L., Csordas, A. (2009) *Molecular Detection of Foodborne Pathogens*, CRC Press.

34 Hoorfar, J. (2011) Rapid detection, characterization, and enumeration of foodborne pathogens. *Apmis*, 119(s133), 1–24.

35 Patrascu, I., Gamble, H., Sofronic-Milosavljevic, L. *et al.* (2001) The lateral flow card test: an alternative method for the detection of *Trichinella* infection in swine. *Parasite*, 8 (2 Suppl), S240–S242.

36 Thiruppathiraja, C., Kamatchiammal, S., Adaikkappan, P. *et al.* (2011) An advanced dual labeled gold nanoparticles probe to detect *Cryptosporidium parvum* using rapid immuno-dot blot assay. *Biosensors and Bioelectronics*, 26(11), 4624–4627.

37 Xu, X., Sui, J., Cao, L. *et al.* (2010) Direct competitive enzyme-linked immunosorbent assay (ELISA) for rapid screening of anisakid larvae in seafood. *Journal of the Science of Food and Agriculture*, 90(5), 877–881.

38 Xu, S., Mutharasan, R. (2010) Rapid and sensitive detection of *Giardia lamblia* using a piezoelectric cantilever biosensor in finished and source waters. *Environmental Science and Technology*, 44(5), 1736–1741.

39 Zarlenga, D. S., Chute, M. B., Martin, A. *et al.* (1999) A multiplex PCR for unequivocal differentiation of all encapsulated and non-encapsulated genotypes of Trichinella. *International Journal of Parasitology*, 29(11), 1859–1867.

40 Chen, J., Tang, J., Liu, J. *et al.* (2012) Development and evaluation of a multiplex PCR for simultaneous detection of five foodborne pathogens. *Journal of Applied Microbiology*, 112(4), 823–830.

41 de Freitas, C. G., Santana, Â. P., da Silva, P. H. C. *et al.* (2010) PCR multiplex for detection of *Salmonella enteritidis*, *Typhi* and *Typhimurium* and occurrence in poultry meat. *International Journal of Food Microbiology*, 139(1), 15–22.

42 Wilson, I. G.(1997) Inhibition and facilitation of nucleic acid amplification. *Applied and Environmental Microbiology*, 63(10), 3741–3751.

43 Powell, H., Gooding, C., Garrett, S. *et al.* (1994) Proteinase inhibition of the detection of Listeria monocytogenes in milk using the polymerase chain reaction. *Letters in Applied Microbiology*, 18(1), 59–61.

44 Rossen, L., Nørskov, P., Holmstrøm, K. *et al.* (1992) Inhibition of PCR by components of food samples, microbial diagnostic assays and DNA-extraction solutions. *International Journal of Food Microbiology*, 17(1), 37–45.

45 Skotarczak, B. (2009) Methods for parasitic protozoans detection in the environmental samples. *Parasite*, 16(3), 183–190.

46 Schwab, K. J., McDevitt, J. J. (2003) Development of a PCR-enzyme immunoassay oligoprobe detection method for *Toxoplasma gondii* oocysts, incorporating PCR controls. *Applied and Environmental Microbiology*, 69(10), 5819–5825.

47 Higuchi, R., Dollinger, G., Walsh, P. S. *et al.* (1992) Simultaneous amplification and detection of specific DNA sequences. *Biotechnology*, 10(4), 413–417.

48 Kerambrun, E., Palos Ladeiro, M., Bigot-Clivot, A. *et al.* (2015) Zebra mussel as a new tool to show evidence of freshwater contamination by waterborne Toxoplasma gondii. *Journal of Applied Microbiology*, 120(2), 498–508.

49 Atterby, H., Learmount, J., Conyers, C. *et al.* (2009) Development of a real-time PCR assay for the detection of *Trichinella spiralis* in situ. *Veterinary Parasitology*, 161(1), 92–98.

50 Lopez, I., Pardo, M. A. (2010) Evaluation of a real-time polymerase chain reaction (PCR) assay for detection of *Anisakis simplex* parasite as a food-borne allergen source in seafood products. *Journal of Agricultural and Food Chemistry*, 58(3), 1469–1477.

51 Ramirez, N. E., Sreevatsan, S. (2006) Development of a sensitive detection system for *Cryptosporidium* in environmental samples. *Veterinary Parasitology*, 136(3), 201–213.

52 Notomi, T., Okayama, H., Masubuchi, H. *et al.* (2000) Loop-mediated isothermal amplification of DNA. *Nucleic Acids Research*, 28(12), e63–e63.

53 Karanis, P., Ongerth, J. (2009) LAMP: A powerful and flexible tool for monitoring microbial pathogens. *Update*, 25(11), 498–499.

54 Arimatsu, Y., Kaewkes, S., Laha, T. *et al.* (2012) Rapid detection of *Opisthorchis viverrini* copro-DNA using loop-mediated isothermal amplification (LAMP). *Parasitology International*, 61(1), 178–182.

55 Sanpool, O., Intapan, P. M., Thanchomnang, T. *et al.* (2012) Rapid detection and differentiation of *Clonorchis sinensis* and *Opisthorchis viverrini* eggs in human fecal samples using a duplex real-time fluorescence resonance energy transfer PCR and melting curve analysis. *Parasitology Research*, 111(1), 89–96.

56 Traub, R. J., Macaranas, J., Mungthin, M. *et al.* (2009) A new PCR-based approach indicates the range of *Clonorchis sinensis* now extends to Central Thailand. *PLoS Neglected Tropical Diseases*, 3(1), 1–7.

57 Cai, X., Xu, M., Wang, Y. *et al.* (2010) Sensitive and rapid detection of *Clonorchis sinensis* infection in fish by loop-mediated isothermal amplification (LAMP). *Parasitology research*, 106(6), 1379–1383.

58 Chen, Y., Wen, T., Lai, D.H. *et al.* (2013) Development and evaluation of loop-mediated isothermal amplification (LAMP) for rapid detection of *Clonorchis sinensis* from its first intermediate hosts, freshwater snails. *Parasitology*, 140(11), 1377–1383.

59 Wang, Z., Vora, G. J., Stenger, D. A. (2004) Detection and genotyping of *Entamoeba histolytica*, *Entamoeba dispar*, *Giardia lamblia*, and *Cryptosporidium parvum* by oligonucleotide microarray. *Journal of Clinical Microbiology*, 42(7), 3262–3271.

60 Brinkman, N., Francisco, R., Nichols, T. *et al.* (2013) Detection of multiple waterborne pathogens using microsequencing arrays. *Journal of Applied Microbiology*, 114(2), 564–573.

61 Chen, J.X., Chen, M.X., Ai, L. *et al.* (2013) An outbreak of human *Fascioliasis gigantica* in southwest China. *PloS One*, 8(8), e71520.

62 Choi, S., Lam, P. (2009) Enhancing legal preparedness for the prevention and control of infectious diseases: Experience from severe acute respiratory syndrome in Hong Kong. *Public Health*, 123(3), 242–246.

63 Zhang, L., Wilson, D. P. (2012) Trends in notifiable infectious diseases in China: implications for surveillance and population health policy. *Plos One*, 7(2), 1–12.

64 USEPA. (Long Term 2 Enhanced Surface Water Treatment Rule (LT2). https://www.epa.gov/dwreginfo/long-term-2-enhanced-surface-water-treatment-rule-documents (access October 2016).

65 Takeuchi, T., Nozaki, S., Crump, A. (2007) Past Japanese successes show the way to accomplish future goals. *Trends in Parasitology*, 23(6), 260–267.

66 Zhou, X.N., Lin, J.J., Cao, J.P. *et al.* (2006) Theory and practices of the infrastructure establishment on parasite germplasm resources in China. *Chinese Journal of Parasitology and Parasitic Diseases*, 35, S1.

67 Wang, L.D., Chen, H.G., Guo, J.G. *et al.* (2009) A strategy to control transmission of Schistosoma japonicum in China. *New England Journal of Medicine*, 360(2), 121–128.

68 Wang, L., Utzinger, J., Zhou, X.N. (2008) Schistosomiasis control: experiences and lessons from China. *The Lancet*, 372(9652), 1793–1795.

69 Utzinger, J., Zhou, X.N., Chen, M.G. *et al.* (2005) Conquering schistosomiasis in China: the long march. *Acta Tropica*, 96(2–3), 69–96.

70 Azam, A., Peerzada, M. N., Ahmad, K. (2015) Parasitic diarrheal disease: drug development and targets. *Frontiers in Microbiology*, 6, 1183.

71 Broglia, A., Kapel, C. (2011) Changing dietary habits in a changing world: emerging drivers for the transmission of foodborne parasitic zoonoses. *Veterinary Parasitology*, 182(1), 2–13.

72 Burke, R., Kronmann, K., Daniels, C. *et al.* (2012) A review of zoonotic disease surveillance supported by the Armed Forces Health Surveillance Center. *Zoonoses and Public Health*, 59(3), 164–175.

73 Angelos, J., Arens, A., Johnson, H. *et al.* (2016) One Health in food safety and security education: A curricular framework. *Comparative Immunology, Microbiology and Infectious Diseases*, 44, 29–33.

74 Eddi, C., Juan, L., William, A. *et al.* (2006) Veterinary public health activities at FAO: cysticercosis and echinococcosis. *Parasitology International*, 55, S305–S308.

75 Ito, A., Urbani, C., Jiamin, Q. *et al.* (2003) Control of echinococcosis and cysticercosis: a public health challenge to international cooperation in China. *Acta Tropica*, 86(1), 3–17.

76 Ryan, C. P. (2007) Where do pets fit into human quarantines? *Journal of Public Health*, 29(1), 70–71.

10

Natural Antimicrobials from Herbs and Spices

P. Michael Davidson

Department of Food Science and Technology, University of Tennessee, USA

10.1 Food Preservation

Food for human consumption is often preserved in some manner to slow or prevent autolytic degradation or undesirable changes caused by oxygen, light, or the growth of spoilage microorganisms. Some of the same preservation processes used to control growth of spoilage microorganisms may also improve food safety by inhibiting or inactivating pathogenic or disease-causing microorganisms. The methods for controlling microorganisms in food for human consumption may be classified based upon whether they prevent contamination by, inactivate or inhibit microorganisms. Sanitation and the prevention of cross-contamination are methods used to reduce or prevent contamination by spoilage or pathogenic microorganisms. They are necessary to allow the other forms of microbial control to function at their optimum. Inactivation methods include the most common preservation method, heat, as well as various so-called "non-thermal" methods such as irradiation, high hydrostatic pressure, pulsed electric fields, pulsed light, and so on. Obviously, these control methods function by inactivating or killing microorganisms, including bacteria, bacterial spores, fungi, viruses and parasites in foods. Inhibition methods are less often severe and generally cause increases in the lag phase of growth of microorganisms or "stasis," whereby growth is stopped, but the microorganism is not necessarily killed. Inhibition methods include the use of cold or freezing, reduced water activity or drying, reduced pH, modified atmosphere packaging, fermentations and the addition of antimicrobial compounds. Some of the inhibition methods can result in inactivation, such as high concentrations of antimicrobial compounds, but they are not generally designed for inactivation.

10.2 Antimicrobial Food Preservatives

Antimicrobial compounds have been used in foods for thousands of years. Ancient peoples used salt and smoke for preserving meat products for later consumption. The use of vinegar, honey and the burning of sulfur to produce sulfur dioxide as a sterilant were practiced in ancient Rome, Egypt, China and Greece. The use of chemical antimicrobials

Food Safety in China: Science, Technology, Management and Regulation, First Edition.
Edited by Joseph J. Jen and Junshi Chen.

to preserve foods increased significantly in the twentieth century. This was likely the result of the desire of consumers for foods with increased shelf life and consistent quality over time. In 1908, benzoic acid became the first antimicrobial preservative approved for foods in the US [1]. At present, the use of antimicrobial food preservatives is fairly common throughout the world to increase shelf life and improve safety of foods. The most common regulatory-approved antimicrobial food preservatives in use are the organic acids including acetic, lactic, propionic, benzoic and sorbic acids or their salts. Historically, regulatory-approved antimicrobial food preservatives have been used to improve shelf life of food products by inhibiting the growth of spoilage microorganisms such as molds, yeasts and bacteria. The only long-term example of using an antimicrobial food preservative for food safety is the use of nitrites to inhibit the growth and toxin production of the pathogen, *Clostridium botulinum,* in cured meats. The general use of antimicrobial food preservatives for controlling food-borne pathogens has only been a part of the food industry over the past 25-30 years.

While they are very useful and toxicologically safe, there are several issues associated with the current regulatory-approved antimicrobials for use in foods. One of the primary shortcomings is spectrum of activity. Many of the regulatory-approved antimicrobial food preservatives are organic acids which are most, or only, effective in the undissociated form. Even some of the inorganic compounds are most effective at lower pH, such as nitrites and sulfites. While that is acceptable for low pH or high acid food products, it leaves a gap for the higher pH, lower acid (> pH 5.0) food products. It is the low acid food products (e.g., meats, vegetables, dairy products and many formulated food products) that are most prone to have food safety problems due to the presence of pathogenic bacteria and to more rapid spoilage by microorganisms. Additionally, many of the regulatory-approved antimicrobials are somewhat selective in their effectiveness. They may be better antifungal agents or be more effective against a certain type of bacteria, such as Gram-positive or Gram-negative bacteria. Another, more recent, phenomenon is the perception by consumers that any "additive" is both unnecessary and potentially hazardous. While there are some potential toxicological issues with certain antimicrobials, such as nitrosamine formation with nitrites under high heat conditions and sensitivity to sulfites in asthmatics, it is not the case for most of the antimicrobial food preservatives. It is for the reasons mentioned above that the food industry has significantly increased their search for antimicrobial compounds that are "natural", that is, come from natural sources, such as spices, herbs and other plants.

10.3 Spices and Herbs as Natural Antimicrobials

Spices and herbs are generally used for flavoring agents in foods, however they are known to contain essential oils (EOs) and essential oil components (EOCs), some of which are known to possess antimicrobial activity (Tables 10.1 and 10.2). There have been literally hundreds of studies on the antimicrobial activity of EOs and EOCs. From these it has been demonstrated that the greatest antimicrobial activity against microorganisms is generally produced by the EOs from cloves, cinnamon, oregano and thyme and their primary EOCs, eugenol, cinnamaldehyde, carvacrol and thymol, respectively [2].

Table 10.1 Antimicrobial activity of selected EOCs [18].

Common name	Scientific Name	Components of EO and/or primary active component	Bacteria Inhibited	Fungi Inhibited
Basil	*Ocimum basilicum*	Linalool, methyl chavicol, methyl cinnamate	*Bacillus* *Enterococcus* *Escherichia coli* *Lactobacillus plantarum* *Pseudomonas* *Salmonella* Enteritidis *Shigella* sp. *Staphylococcus* *Vibrio parahemolyticus*	*Aspergillus* *Candida* *Mucor* *Geotrichum candidum*
Cinnamon	*Cinnamomum zeylanicum*	Cinnamaldehyde, benzaldehyde, cinnamyl acetate	*Aeromonas hydrophila* *Bacillus* *Bacillus subtilis* *E. coli* *E. coli* O157:H7 *Endomyces fibuliger* *Lactobacillus* *Listeria innocua* *Listeria monocytogenes* *Salmonella enterica* *Staphylococcus aureus* *Streptococcus*	*Aspergillus* *Aspergillus flavus* *Candida* *Candida albicans* *Penicillium commune* *Penicillium roqueforti* *Saccharomyces cerevisiae*
Clove	*Syzygium aromaticum*	Eugenol	*Aeromonas hydrophila* *Bacillus* *Bacillus subtilis* *E. coli* *E. coli* O157:H7 *Listeria monocytogenes* *Listeria innocua* *Salmonella enterica*	*Aspergillus* *Aspergillus flavus* *Candida* *Endomyces fibuliger* *Penicillium commune* *Penicillium roqueforti* *Saccharomyces cerevisiae*

(Continued)

Table 10.1 (Continued)

Common name	Scientific Name	Components of EO and/or primary active component	Bacteria Inhibited	Fungi Inhibited
			Salmonella Enteritidis *Salmonella* Typhimurium *Shigella* sp. *Staphylococcus aureus*	
Coriander; Cilantro	*Coriandrum sativum*	Linalool	*Listeria monocytogenes* *Staphylococcus aureus*	*Saccharomyces cerevisiae*
Oregano	*Origanum vulgare*	Carvacrol Terpinen-4-ol Linalool Sabinene Alpha-terpinene Gamma-terpinene p-Cymene Beta-caryophyllene Limonene Alpha-pinene Thymol	*Acinetobacter baumanii* *Aeromonas veronii* *Bacillus subtilis* *E. coli* Enterotoxigenic *E. coli* *Enterococus faecalis* *Klebsiella pneumoniae* *Listeria monocytogenes* *Pseudomonas aeruginosa* *Salmonella enterica* *Salmonella* Enteritidis *Salmonella* Typhimurium *Serratia marcescens* *Shigella sp.* *Staphylococcus aureus* *S. aureus, Methicillin resistant*	*Candida albicans* *Penicillium digitatum* *Saccharomyces cerevisiae*

Table 10.1 (Continued)

Common name	Scientific Name	Components of EO and/or primary active component	Bacteria Inhibited	Fungi Inhibited
Rosemary	*Rosmarinus officinalis*	Borneol (endo-1,7,7-trimethylbicyclo [2.2.1] heptan-2-ol) Pinene Camphene Camphor	*Shigella* sp.	*Aspergillus*
Sage, Garden	*Salvia officinalis*	Thujone (4-methyl-1-[1-methylethyl] bicyclo[3.1.0]-hexan-3-one)	Lactobacilli *Vibrio parahemolyticus*	
Thyme, Common	*Thymus vulgaris*	thymol carvacrol borneol	*Aeromonas hydrophila* *Brochothrix thermosphacta* *E. coli* *Escherichia coli O157:H7* lactic acid bacteria *Listeria monocytogenes* *Salmonella enterica* *Salmonella* Enteritidis *Salmonella* Typhimurium *Shigella flexneri* *Shigella sp.* *Staphylococcus aureus* *Yersinia enterocolitica*	*Botrytis cinerea* *Candida albicans* *Penicillium digitatum* *Rhizopus stolonifer*
Vanilla	*Vanilla planifolia*; syn. *Vanilla fragrans; Vanilla tahitensis; Vanilla pompona*			*Aspergillus flavus* *Aspergillus niger* *Aspergillus ochraceus*

(Continued)

Table 10.1 (Continued)

Common name	Scientific Name	Components of EO and/or primary active component	Bacteria Inhibited	Fungi Inhibited
				Aspergillus parasiticus *Penicillim glabrum* *Penicillium digitatum* *Penicillium italicum*

Eugenol (2-methoxy-4-(2-propenyl)-phenol) is the major antimicrobial in clove bud (*Syzygium aromaticum*), comprising approximately 70–90% of the oil. The remainder of the oil contains compounds such as eugenol acetate (0–15%) and beta caryophyllene (5–15%) [3, 4]. Clove EO and eugenol have been shown to be inhibitory to *Aeromonas*

Table 10.2 Antimicrobial spectrum of activity of EOCs of herbs and spices [18]

Essential oil component	Primary source	Gram-positive bacteria inhibited	Gram-negative bacteria inhibited	Fungi and other microorganisms inhibited
Carvacrol (5-isopropyl-2-methylphenol)	Oregano	*Bacillus cereus* *Bacillus subtilis* *Listeria innocua* *Listeria monocytogenes* Methicillin-resistant *Staphylococcus aureus* *Staphylococcus aureus*	*Campylobacter jejuni* *Escherichia coli* O157:H7 *Pseudomonas aeruginosa* *Salmonella enterica* *Salmonella* Typhimurium	*Aspergillus flavus* *Candida albicans*
Cinnamaldehyde ((2*E*)-3-phenylprop-2-enal)	Cinnamon	*Listeria monocytogenes*	*Campylobacter jejuni* *E. coli* *Escherichia coli* O157:H7 *Salmonella entérica* *Salmonella* Enteritidis *Salmonella* Typhimurium	*Candida albicans*

Table 10.2 (Continued)

Essential oil component	Primary source	Gram-positive bacteria inhibited	Gram-negative bacteria inhibited	Fungi and other microorganisms inhibited
Eugenol (2-methoxy-4-(2-propenyl)-phenol)	Cloves	*Bacillus subtilis* *Lactobacillus sakei* *Listeria innocua* *Listeria monocytogenes* *Staphylococcus aureus*	*Aeromonas hydrophila* *Campylobacter jejuni* *E. coli* *Escherichia coli* O157:H7 *Salmonella enterica* *Salmonella* Typhimurium	*Aspergillus flavus* *Candida albicans* *Saccharomyces cerevisiae*
Perillaldehyde ((*S*)-4-(1-methylethenyl)-1-cyclohexene-1-carboxaldehyde)	Perilla	*Listeria monocytogenes*	*Campylobacter jejuni* *E. coli* *Salmonella* Typhimurium	
Thymol (2-isopropyl-5-methylphenol)	Thyme	*Bacillus cereus* *Bacillus licheniformis* *Bacillus subtilis* *Lactobacillus curvatus* *Lactobacillus plantarum* *Listeria innocua* *Listeria monocytogenes* *Staphylococcus aureus* Methicillin-resistant *Staphylococcus aureus*	*Campylobacter jejuni* *Escherichia coli* O157:H7 *Pseudomonas aeruginosa* *Salmonella enterica* *Salmonella* Typhimurium	*Aspergillus flavus* *Candida lusitaniae* *Pichia subpelliculosa* *Saccharomyces cerevisiae*

hydrophila, Bacillus spp., *Campylobacter jejuni, Escherichia coli* O157:H7 and other Shiga-toxigenic *E. coli, Lactobacillus, Listeria monocytogenes,* Salmonellae, *Shigella* spp., *Staphylococcus aureus* and *Streptococcus,* and the fungi *Aspergillus, Candida, Penicillium* and *Saccharomyces,* among other microorganisms [5–10]. Clove EO and eugenol have also been evaluated against pathogenic bacteria in food products. For example, 0.3% cinnamon extract in apple juice reduced *E. coli* O157:H7 by ~2.0 log CFU/ml at 8 °C and when used in combination with 0.1% sodium benzoate or potassium sorbate, the bacterium was reduced to non-detectable levels [11]. The effectiveness of clove EO on foods is highly dependent upon the type of food and the application method. *Listeria monocytogenes* was significantly lower on chicken frankfurters with

1 to 2% clove essential oil at 5 or 15 °C than on untreated inoculated control frankfurters [12]. In contrast, Singh *et al.* [13] found that dipping franks into aqueous clove essential oil solutions for up to 10 min did not significantly inhibit *L. monocytogenes*. Eugenol has demonstrated antimicrobial activity against pathogens on the surfaces of cooked beef, pork and poultry [14–16].

The antimicrobial activity of cinnamon EO (*Cinnamomum zeylanicum*), is attributed to primarily to the EOC, cinnamic aldehyde (3-phenyl-2-propenal). Cinnamon bark contains 0.5–10% volatile oil which contains 69–75% cinnamic aldehyde, eugenol, benzaldehyde and cinnamyl acetate [17]. Cinnamon and cinnamic aldehyde are generally the most effective antimicrobials among the spice EOs and EOCs, respectively. Cinnamon and cinnamic aldehyde have demonstrated antimicrobial activity against a similar range of bacteria as clove EO and eugenol [18]. Adding 0.3% cinnamon extract to apple juice and holding at 8 °C reduced numbers of *E. coli* O157:H7 by ~2.0 log10 CFU/ml; when used in combination with 0.1% sodium benzoate or potassium sorbate, the pathogen populations were reduced to non-detectable levels [11]. Alginate coatings containing 0.3 or 0.7% cinnamon extract or 0.5% purified eugenol and malic acid inhibited growth of *S.* Enteriditis, psychrophilic and mesophilic bacteria, and food-borne yeasts and molds [19]. Growth of yeasts and molds was completely inhibited when films containing 0.7% cinnamon or 0.5% eugenol were applied [19].

Oregano (*Origanum vulgare*) is a commonly used spice in the Mediterranean Basin, Philippines and Latin American cuisines. Distillation of dried oregano can extract oregano EO [20]. Carvacrol (2-methyl-5-(1-methylethyl)-phenol), accounts for 60–70% of oregano EO. Thymol (5-methyl-2-(1-methyl)-phenol), γ-terpinene (4-methyl-1-(1-methylethyl)-1,4-cyclohexadiene) and ρ-cymene (1-methyl-4-(1-methylethyl) benzene), are the remaining components of oregano EO [17]. Oregano EOs and carvacrol have antimicrobial activity against many spoilage and pathogenic food-borne microorganisms, including *A. hydrophila*, *Bacillus*, *C. jejuni*, *E. coli*, *Enterococcus* spp., *Lactobacillus*, *L. monocytogenes*, *Pediococcus*, *Pseudomonas* spp., *Salmonella*, *Shigella*, *S. aureus*, *Vibrio parahemolyticus*, *Y. enterocolitica*, *Aspergillus*, *Candida*, *Geotrichum*, *Penicillium*, *Pichia*, *Rhodotorula*, *Saccharomyces* and *Schizosaccharomyces pombe* [1, 21–24]. The minimum inhibitory concentrations of oregano EO determined by a microbroth dilution assay at 37 °C for 18 h in TSB were 500, 400, 200 and 200,000 mg/l, respectively, against *B. cereus*, *E. coli*, *L. monocytogenes*, and *Pseudomonas aeruginosa* [25]. Biofilm formation by *S. aureus* was decreased in the presence of 0.0125% oregano EO after for 24 h at 37 °C [26]. Oregano EO at 0.05 to 1% in combination with modified-atmosphere packaging was able to inhibit the growth of *Brochothrix thermosphacta* in minced meat stored at 5 °C. Additionally, sensory analysis of the minced meat with 1% oregano concluded that the odor of the EO in minced meat was not detected by panelists [27]. Similarly, oregano EO at 0.8% in combination with modified packaging conditions caused a 2–3 log reduction of *L. monocytogenes* on meat at 5 °C [28]. Cod and salmon fillets with 0.05% OEO in modified atmosphere packaging stored at 2 °C inhibited the growth of the spoilage microorganism *Photobacterium phosphoreum* [29].

The antimicrobial activity of thyme EO is likely due to thymol which is present at around 45% [6], as well as carvacrol, which can range from 33% in leaf oils to about 61% in stem oil, depending on geographic location, time of harvest or extraction method of the oil [30]. Thyme EO and thymol have been shown to inhibit the bacteria *Aeromonas* *hydrophila, Brochothrix thermosphacta, Campylobacter jejuni, Escherichia coli* O157:H7, *Pseudomonas aeruginosa, Salmonella enterica, Salmonella* Typhimurium, *Bacillus cereus, Bacillus licheniformis, Bacillus subtilis, Lactobacillus curvatus, Lactobacillus plantarum, Listeria innocua, Listeria monocytogenes, Staphylococcus aureus,* methicillin-resistant *Staphylococcus aureus, Aspergillus flavus, Candida lusitaniae, Pichia subpelliculosa, Saccharomyces cerevisiae, Shigella flexneri,* and *Yersinia enterocolitica* [18]. 500 ppm thyme oil reduced the total population of *Aspergillus flavus* by 87.5% compared to the initial count of 10^5 CFU/ml in culture medium [31].

Rosemary (*Rosmarinus officinalis*), which contains borneol (endo-1,7,7-trimethylbicyclo[2.2.1]-heptan-2-ol), pinene, camphene and camphor, and sage (*Salvia officinalis*), which contains thujone (4-methyl-1-(1-methylethyl)-bicyclo[3.1.0]-hexan-3-one) also have antimicrobial activity [1]. Pandit and Shelef [32] reported that rosemary was the most effective of 18 spices added to culture medium to inhibit *L. monocytogenes.* Gutierrez *et al.* [23] determined that the minimum inhibitory concentrations (MICs) of rosemary and sage against *Listeria* and *Staphylococcus* spp. ranged from 300 to 10,000 ppm, whereas the MICs against *E. coli* and *Pseudomonas* spp. were >10,000 ppm. MICs in broth of rosemary extract were 150 to 600 µg/ml against *Leuconostoc, Brochothrix, Carnobacterium,* and *Lactobacillus.* However, Valero *et al.* [33] determined that sage and rosemary were no more effective at inhibiting *B. cereus* in carrot juice than were oregano, clove or thyme. Similarly, when applied singly or in combination on fresh pork meat, rosemary and sage had no significant antimicrobial activity against food-borne microbial populations [23]. Similar losses of antimicrobial efficacy of sage and rosemary extracts applied in other food systems were reported by Shelef *et al.* [34].

Basil (*Ocimum basilicum*) is an herb which prefers a warm and temperate climate for growth. Cultivation originated in India and tropical Asia, but it is now cultivated commercially in several European countries, including France, Greece and Egypt, and multiple areas of the United States [35]. The composition of basil EO has great variation depending on variety, geographic location and time of harvest. Major components reported include linalool (35–60%), geraniol (35–45%), eugenol (20–25%), methyl chavicol (38–50%) and camphor (20%) [35]. Basil has shown inhibitory effects against both bacteria and fungi, including *Bacillus, Escherichia coli, Staphylococcus* and *Aspergillus* [18]. In a study conducted by Bagamboula *et al.* [36], 10% (v/v) of basil EO inhibited the growth of *Shigella flexner*i, *S. sonnei* and *E. coli* in an agar well diffusion assay. In this particular study, basil EO was shown to be composed of 16.1% linalool and no trace of eugenol. The antimicrobial activity of seasonal variations of basil EO was compared in a study by Hussain *et al.* [37]. All seasonal variations of basil EO had approximately 60% linalool. Basil EO inhibited the growth of *S. aureus* (MIC 1.3 mg/ml), *E. coli* (MIC 2.6 mg/ml), *B. subtilis* (MIC 1.4 mg/ml), *Penicillium multocida* (MIC 1.9 mg/ml), *Aspergillus niger* (MIC 3.2 mg/ml), *Mucor mucedo* (MIC 4.9 mg/ml) and *Fusarium solani* (MIC 3.6 mg/ml) in a microbroth dilution assay [37]. Maize kernels coated with 5% basil EO inhibited growth of *Aspergillus flavus* [38]. Basil EO in combination with olive oil increased the death rate of *S.* Enteriditis in mayonnaise at pH 4.3 stored at 4 °C and 20 °C [39]. Adding basil EO (100 ppm) to nham, a Thai dish, reduced *S.* Enteriditis to non-detectable levels with no regrowth of the pathogen during refrigerated storage [40]. Applying basil EO to minced meat reduced food-borne bacterial pathogens by approximately 1.0 log CFU/g, however, basil essential oil was no more effective than other spice extracts applied [41].

Vanillin (4-hydroxy-3-methoxybenzaldehyde) is a major constituent of the vanilla bean, the fruit of an orchid (*Vanilla planifolia*, *Vanilla pompona* or *Vanilla tahitensis*). Vanillin is active against molds and some Gram-positive bacteria. In vitro, vanillin at 1500 ppm significantly inhibited *Aspergillus niger*, *A. flavus* and *A. parasiticus* growth [42]. Vanillin alone or in combination with other antimicrobials preserved strawberry purée against inoculated yeasts and background microorganisms [43]. Vanillin has been used with other antimicrobials and physical processes to preserve or improve the safety of foods. Addition of a combination of vanillin and citral to orange juice followed by exposure to mild heating decreased the time required for pasteurization based on a ≥5.0 log CFU/ml reduction of *Listeria innocua* [44]. A combined treatment of vanillin and high-hydrostatic-pressure processing (100 to 300 MPa) resulted in bacteriostatic inhibition of *B. cereus* in liquid whole eggs [45]. Finally, vanillin in combination with caprylic acid inactivated *Cronobacter sakazakii* and *S.* Typhimurium in reconstituted infant formula at a greater rate than either one alone [46].

Coriander (*Coriandrum sativum* L.) is an herb and spice native to the Mediterranean and Middle East. The leaves are more commonly referred to as cilantro, while the seeds are called coriander. Coriander EO (CEO) is derived from the seeds [47]. Linalool (65–90%) and α-pinene (2,6,6-trimethylbicyclo [3.1.1] hept-2-ene) (5–90%) are the primary antimicrobial components of CEO [48], which is reported to have antimicrobial activity against bacteria and yeasts [18]. A study conducted by Delaquis *et al.* [48] found CEO (≤0.5 % v/v) in a microbroth dilution assay in TSBYE had antimicrobial activity against *Listeria monocytogenes*, *Staphylococcus aureus*, *Saccharomyces cerevisiae*, *Pseudomonas fragi* and *Salmonella* Typhimurium at 30 °C at 48 h. CEO has also been shown to have antimicrobial activity in food matrix studies. Stecchini *et al.* [16] applied 1250 μg/ml CEO to uncured cooked pork inoculated with *Aeromonas hydrophila*. Samples were stored at 2 and 10 °C under vacuum or air packaging. The addition of CEO reduced the growth of *A. hydrophila* by 5 logs. In another study [49], CEO was homogenized with lean beef and chicken breast inoculated with 5 log CFU/ml of *Campylobacter jejuni*, which caused a reduction of cell counts to an undetectable level after 30 min at 4 °C and 32 °C. One unusual characteristic of CEO is its potential chelating activity. Ahlers [50] showed that, at the MIC of CEO (1.0%), a high chelation of ferrous ions occurred, which could inhibit those microorgnisms requiring iron.

Other EOs or extracts from basil, bay, citrus, cumin, dill, fingerroot (*Boesenbergia pandurata*), laurel, lemongrass (*Cymbopogon citratus*), marjoram, melissa, nutmeg, perilla (*Perilla frutescens*) savory (*Satureja* spp.), tea tree oil (*Melaleuca alternifolia*), vervain and yerba mate have demonstrated moderate to high activities in some studies against selected microorganisms [16, 21, 24]. Relatively little antimicrobial activity has been observed for many other spice-bearing plants, including anise, black pepper, cardamom, cayenne, celery, chili, curry, dill, fenugreek, ginger, juniper oil, mace, orris root, paprika, sesame, spearmint, tarragon, turmeric and white pepper [51].

10.4 Considerations in Using Essential Oils as Natural Antimicrobials in Foods

A number of potential issues must be addressed in determining whether EOs or EOCs can be successfully applied to foods for use as antimicrobials, including toxicological effects, cost, influence of food components on activity and sensory effects. These issues are covered in depth in David *et al.* [52] and Davidson *et al.* [53]. Toxicological safety of any food additive is important. Consumption of EOs and EOCs may not cause adverse effects at the levels present for flavoring, they could have a greater chance of toxicity at the higher concentrations required to achieve antimicrobial activity. However, according to Peter and Shylaja [54] even greater intake of most spices would not likely lead to toxic effects and in fact many EOs have reported beneficial medicinal properties. Among the medicinal properties attributed to EOs include their positive effects on the gastrointestinal system as well as carminative, stimulatory, anti-inflammatory, aphrodisiac, diuretic, antirheumatic, analgesic and antidepressive effects, among others [54]. In addition to antimicrobial activity, a successful antimicrobial needs to have a reasonable "cost-in-use" [52]. The addition of EOs or EOCs as antimicrobials likely will increase the cost for a finished food product compared to use of synthetic antimicrobials. The improved safety, increased shelf life, and "clean label" factors of the EO or EOC must be weighed against the increased costs. According to David *et al.* [52], an increased shelf-life of at least two to three days for a product could offset the cost of an antimicrobial, depending on the type of food. Physicochemical properties of EOs and EOCs, especially polarity, directly relate to the interactions of such compounds with microorganisms as well as food components [55]. EOs and EOCs that have been shown to have high antimicrobial activity in vitro often have little to no effect against microbial targets at similar concentrations when incorporated into food systems [53]. This is because of interactions with food components [22, 25, 56]. Plant essential oils are amphiphilic (partially hydrophobic and partially hydrophilic). Hydrophilic portions of antimicrobials are necessary for a compound to solubilize in the water phase where microorganisms are present, while lipophilic portions are required for interaction of a compound with microbial cell membrane comprised of phospholipids [57]. However, that same amphiphilic character can result in antimicrobials interacting with or being solubilized by hydrophobic components of foods, such as lipids or hydrophobic portions of proteins. This makes them unavailable to react with microorganisms. Food components, including proteins [58], lipids [25, 59–61] and carbohydrates [25] have been shown to interact with antimicrobials resulting in a reduced activity. Because of their hydrophobicity, there is nearly always a need to increase the concentration of essential oils when used as antimicrobials in foods versus microbiological media. This is especially true in foods with high lipid and/or protein content that may affect the partitioning of essential oil components into the lipid and/or protein phases of the food. Encapsulation technologies may overcome such interactions between food components and antimicrobial essential oils [62–65]. The influence of EOs and EOCs on the sensory characteristics (e.g., flavor, odor) of a food is a main limiting factor for these compounds. Depending on the food and the EO or EOC, changes in flavor or odor may be desirable or highly undesirable. The sensory compatibility of an EO or EOC needs to be carefully considered (e.g., oregano EO would not necessarily be compatible with a dairy product). High concentrations of most EOs and EOCs are usually required to achieve significant antimicrobial activity in foods, thus causing potentially unacceptable off-odors or off-flavors [1]. The use of combinations of EOs and EOCs may positively affect antimicrobial activity and be beneficial for reduction of sensory impact by reducing use levels [52, 66–68].

References

1 Davidson, P.M., Taylor, T.M. and Schmidt, S.E. (2013) Chemical preservatives and natural antimicrobial compounds, in *Food Microbiology: Fundamentals and Frontiers* 4th edn (eds M.P. Doyle and R.L. Buchanan). American Society for Microbiology, Washington, DC, pp. 765–801.

2 Dorman, H. and Deans, S. (2000) Antimicrobial agents from plants: antibacterial activity of plant volatile oils. *J. Appl. Microbiol.* 88, 308–316.

3 Alma, M.H., Ertas, M., Nitz, S. and Kollmannsberger, H. (2007) Chemical composition and content of essential oil from the bud of cultivated Turkish clove (*Syzygium aromaticum* L.). *BioResources* 2, 265–269.

4 Pino, J.A., Marbot, R., Agüero, J. and Fuentes, V. (2001) Essential oil from buds and leaves of clove (*Syzygium aromaticum* (L.) Merr. et Perry) grown in Cuba. *J. Essential Oil Res.* 13, 278–279.

5 Aureli, P., Costantini, A. and Zolea, S. (1992) Antimicrobial activity of some plant essential oils against *Listeria monocytogenes*. *J. Food Prot.* 55, 344–348.

6 Bagamboula, C. F., Uyttendaele, M., and Debevere, J. (2003) Antimicrobial effect of spices and herbs on *Shigella sonnei* and *Shigella flexneri*. *J. Food Prot.* 66, 668–673.

7 Bennis, S., Chami, F. Chami, N. *et al.* (2004) Surface alteration of *Saccharomyces cerevisiae* induced by thymol and eugenol. *Lett. Appl. Microbiol.* 38, 454–458.

8 Friedman, M., Buick, R. and Elliott, C.T. (2004) Antibacterial activities of naturally occurring compounds against antibiotic-resistant *Bacillus cereus* vegetative cells and spores, *Escherichia coli*, and *Staphylococcus aureus*. *J. Food Prot.* 67, 1774–1778.

9 López-Malo, A., Alzamora, S.M. and Palou, E. (2002) *Aspergillus flavus* dose-response curves to selected natural and synthetic antimicrobials. *Int. J. Food Microbiol.* 73, 213–218.

10 Santiesteban-López, A., Palou, E. and López-Malo, A. (2007) Susceptibility of food-borne bacteria to binary combinations of antimicrobials at selected a_w and pH. *J. Appl. Microbiol.* 102, 486–497.

11 Ceylan, E., Fung, D.Y.C. and Sabah, J.R. (2004) Antimicrobial activity and synergistic effect of cinnamon with sodium benzoate or potassium sorbate in controlling *Escherichia coli* O157:H7 in apple juice. *J. Food Sci.* 69, M102–M106.

12 Mytle, N., Anderson, G.L., Doyle, M.P. and Smith M.A. (2006) Antimicrobial activity of clove (*Syzygium aromaticum*) oil in inhibiting *Listeria monocytogenes* on chicken frankfurters. *Food Control* 17, 102–107.

13 Singh, A.K., Singh, R.K., Bhunia, A.K. and Singh, N. (2003) Efficacy of plant essential oils as antimicrobial agents against *Listeria monocytogenes* in hotdogs. *Lebenson. Wiss. Technol.* 36, 787–794.

14 Hao, Y. Y., Brackett, R.E. and Doyle, M.P. (1998) Efficacy of plant extracts in inhibiting *Aeromonas hydrophila* and *Listeria monocytogenes* in refrigerated, cooked poultry. *Food Microbiol.* 15, 367–378.

15 Hao, Y. Y., Brackett, R.E. and Doyle, M.P. (1998) Inhibition of *Listeria monocytogenes* and *Aeromonas hydrophila* by plant extracts in refrigerated cooked beef. *J. Food Prot.* 61, 307–312.

16 Stecchini, M. L., Sarais, I. and Giavedoni, P. (1993) Effect of essential oils on *Aeromonas hydrophila* in a culture medium and in cooked pork. *J. Food Prot.* 56, 406–409.

17 Vigil, A.L.M., Palou, E. and Alzamora, S. (2005) Naturally occurring compounds – plant sources, in *Antimicrobials in Food*, 3rd edn (eds P.M. Davidson, J.N. Sofos, and A.L. Branen), CRC Press, Boca Raton, FL.

18 Davidson, P.M., F.J. Critzer and T.M. Taylor (2013) Naturally occurring antimicrobials for minimally processed foods. *Ann. Rev. Food Sci. Technol.* 4, 163–190.

19 Raybaudi-Massilia, R. M., Mosqueda-Megar, J. and Martín-Belloso, O. (2008) Edible alginate-based coating as carrier of antimicrobials to improve shelf-life and safety of fresh-cut melon. *Int. J. Food Microbiol.* 121, 313–327.

20 Knobloch, K., Pauli, A., Iberl, B., *et al.* (1989) Antibacterial and antifungal properties of essential oil components. *J. Essential Oil Res.* 1, 119–128.

21 Burt, S. (2004) Essential oils: their antibacterial properties and potential applications in foods: A review. *Int. J. Food Microbiol.* 94, 223–253.

22 Gutierrez, J., Barry-Ryan, C. and Bourke, P. (2009) Antimicrobial activity of plant essential oils using food model media: efficacy, synergistic potential and interactions with food components. *Food Microbiol.* 26, 142–150.

23 Gutierrez, J., Rodriguez, G., Barry-Ryan, C. and Bourke, P. (2008) Efficacy of plant essential oils against foodborne pathogens and spoilage bacteria associated with ready-to-eat vegetables: antimicrobial and sensory screening. *J. Food Prot.* 71, 1846–1854.

24 López-Malo, A., Palou, E. and Alzamora, S.M. (2005) Naturally occurring compounds – plant sources, in *Antimicrobials in Food*, 3rd edn (eds P.M. Davidson, J.N. Sofos, and A.L. Branen), CRC Press, Boca Raton, FL, pp. 429–452.

25 Gutierrez, J., Barry-Ryan, C. and Bourke, P. (2008) The antimicrobial efficacy of plant essential oil combinations and interactions with food ingredients. *Int. J. Food Microbiol.* 124, 91–97.

26 Nostro, A., Roccaro, A.S., Bisignano, G., *et al.* (2007) Effects of oregano, carvacrol and thymol on *Staphylococcus aureus* and *Staphylococcus epidermidis* biofilms. *J. Med. Microbiol.* 56, 519–523.

27 Skandamis, P.N. and Nychas, G.J.E. (2001) Effect of oregano essential oil on microbiological and physico-chemical attributes of minced meat stored in air and modified atmospheres. *J. Appl. Microbiol.* 91, 1011–1022.

28 Tsigarida, E., Skandamis, P. and Nychas, G.J.E. (2000) Behaviour of *Listeria monocytogenes* and autocthonous flora on meat stored under aerobic, vacuum and modified atmosphere packaging condition with or without the presence of oregano essential oil at 5C. *J. Appl. Microbiol.* 89, 901–909.

29 Mejlholm, O. and Dalgaard, P. (2002) Antimicrobial effect of essential oils on the seafood spoilage micro-organism *Photobacterium phosphoreum* in liquid media and fish products. *Lett. Appl. Microbiol.* 34, 27–31.

30 Belaqziz, R., Bahri, F., Romane, A., *et al.* (2013) Essential oil composition and antibacterial activity of the different parts of *Thymus maroccanus* Ball: an endemic species in Morocco. *Natural Prod. Res.* 27, 1700–1704.

31 Omidbeygi, M., Barzegar, M., Hamidi, Z. and Naghdibadi, H. (2007) Antifungal activity of thyme, summer savory and clove essential oils against *Aspergillus flavus* in liquid medium and tomato paste. *Food Control* 18, 1518–1523.

32 Pandit, V.A. and Shelef, L.A. (1994) Sensitivity of *Listeria monocytogenes* to rosemary (*Rosmarinus officianalis* L.). *Food Microbiol.* 11, 57–63.

33 Valero, M. and Salmerón, M.C. (2003) Antibacterial activity of 11 essential oils against *Bacillus cereus* in tyndallized carrot broth. *Int. J. Food Microbiol.* 85, 78–81.

34 Shelef, L. A., Jyothi, E.K. and Bulgarelli, M.A. (1984) Growth of enteropathogenic and spoilage bacteria in sage-containing broth and foods. *J. Food Sci.* 49, 737–740.

35 Pushpangadan, P. and George, V. (2012) Basil, in *Handbook of Herbs and Spices*, 2nd edn (ed. K.V. Peter), Woodhead Publishing Limited, Cambridge, UK.

36 Bagamboula, C. F., Uyttendaele, M. and Debevere, J. (2004) Inhibitory effect of thyme and basil essential oils, carvacrol, thymol, estragol, linalool and p-cymene towards *Shigella sonnei* and *S. flexneri*. *Food Microbiol.* 21, 33–42.

37 Hussain, A.I., Anwar, F., Hussain Sherazi, S.T. and Przybylski, R. (2008) Chemical composition, antioxidant and antimicrobial activities of basil (*Ocimum basilicum*) essential oils depends on seasonal variations. *Food Chem.* 108, 986–995.

38 Montes-Belmont, R. and Carvajal, M. (1998) Control of *Aspergillus flavus* in maize with plant essential oils and their components. *J. Food Prot.* 61, 616–619.

39 Lock, J., and Board, R. (1995) The influence of acidulants and oils on autosterilization of home-made mayonnaise. *Food Res. Int.* 28, 569–572.

40 Rattanachaikunsopon, P. and Phurnkhachorn, P. (2010) Antimicrobial activity of basil (*Ocimum basilicum*) oil against *Salmonella* Enteriditis in vitro and in food. *Biosci. Biotechnol. Biochem.* 74, 1200–1204.

41 Barbosa, L.N., Rall, V.L., Fernandes, A.A., *et al.* (2009) Essential oils against foodborne pathogens and spoilage bacteria in minced meat. *Foodborne Pathog. Dis.* 6, 725–728.

42 López-Malo, A., Alzamora, S. M. and Argaiz, A. (1995) Effect of natural vanillin on germination time and radial growth of moulds in fruit-based agar systems. *Food Microbiol.* 12, 213–219.

43 Cerrutti, P., Alzamora, S. M. and Vidales, S.L. (1997) Vanillin as an antimicrobial for producing shelf-stable strawberry purées. *J. Food Sci.* 62, 608–610.

44 Char, C. D., Guerrero, S.N. and Alzamora, S.M. (2010) Mild thermal process combined with vanillin plus citral to help shorten the inactivation time for *Listeria innocua* in orange juice. *Food Bioprocess. Technol.* 3, 752–761.

45 Pina-Pérez, M.C., Silva-Angulo, A.B. Muguerza-Marquínez, B., *et al.* (2009) Synergistic effect of high hydrostatic pressure and natural antimicrobials on inactivation kinetics of *Bacillus cereus* in a liquid whole egg and skim milk mixed beverage. *Foodborne Pathog. Dis.* 6, 649–656.

46 Choi, M.J., Kim, S.A. Lee, N.Y. and Rhee, M.S. (2013) New decontamination method based on caprylic acid in combination with citric acid or vanillin for eliminating *Cronobacter sakazakii* and *Salmonella enterica* serovar Typhimurium in reconstituted infant formula. *Intl. J. Food Microbiol.* 166, 499–507.

47 Sharma, M. and Sharma, R. (2012) Coriander, in *Handbook of Herbs and Spices*, 2nd edn (ed. K.V. Peter), Woodhead Publishing Limited, Cambridge, UK.

48 Delaquis, P.J., Stanich, K., Girard, B. and Mazza, G. (2002) Antimicrobial activity of individual and mixed fractions of dill, cilantro, coriander and eucalyptus essential oils. *Int. J. Food Microbiol.* 74, 101–109.

49 Rattanachaikunsopon, P. and Phurnkhachorn, P. (2010) Potential of coriander (*Coriandrum sativum*) oil as a natural antimicrobial compound in controlling *Campylobacter jejuni* in raw meat. *Biosci. Biotechnol. Biochem.* 74, 31–35.

50 Ahlers, A.-S. (2016) Characterization of the antimicrobial activity of coriander essential oil against foodborne pathogenic bacteria. Bachelor's thesis, Universität Hohenheim Institut für Lebensmittelwissenschaft und Biotechnologie, Stuttgart, Germany.

51 Davidson, P.M. and Naidu, A.S. 2000. Phyto-phenols, in *Natural Food Antimicrobial Systems,* (ed A.S. Naidu) CRC Press, Boca Raton, FL. pp. 266–294.

52 David, J.R.D., Steenson, L.R. and Davidson, P.M. (2013) Expectations and applications of natural antimicrobials to foods: a guidance document for users, suppliers, research and development and regulatory agencies. *Food Prot. Trends*, 33, 238–247.

53 Davidson, P.M., Bozkurt Cekmer, H., Monu, E. and Techathuvanan, C. (2014). The use of natural antimicrobials in food: An overview, in *Handbook of Natural Antimicrobials for Food Safety and Quality,* (ed. T.M. Taylor), Woodhead Publishing/Elsevier, Cambridge, UK. pp. 1–26.

54 Peter, K.V. and M.R. Shylaja (2012) Introduction to herbs and spices: medicinal uses and sustainable production, in *Handbook of Herbs and Spices*, 2nd edn (ed. K.V. Peter), Woodhead Publishing Limited, Cambridge, UK.

55 Friedman, M., P.R. Henika, C.E. Levin and R.E. Mandrell. (2004) Antibacterial activities of plant essential oils and their components against *Escherichia coli* O157:H7 and *Salmonella* enterica in apple juice. *J. Agric. and Food Chem.* 52, 6042–6048.

56 Hyldgaard, M., Mygind, T. and Meyer, R.L. (2012) Essential oils in food preservation: mode of action, synergies, and interactions with food matrix components. *Front. Microbiol.* 3, 1–24.

57 Davidson, P.M. and Branen, A.L. (2005) Antimicrobials in foods – An introduction. in *Antimicrobials in Food*, 3rd edn (eds P.M. Davidson, J.N. Sofos, and A.L. Branen), CRC Press, Boca Raton, FL.

58 Von Staszewski, M. and Jagus, R.J. (2008) Natural antimicrobials: Effect of Microgard™ and nisin against *Listeria innocua* in liquid cheese whey. *Int. Dairy J.,* 18, 255–259.

59 Cava-Roda, R.M., Taboada-Rodríguez, A., Valverde-Franco, M.T. and Marín-Iniesta, F. (2012) Antimicrobial activity of vanillin and mixtures with cinnamon and clove essential oils in controlling *Listeria monocytogenes* and *Escherichia coli* O157:H7 in milk. *Food Bioproc. Technol.* 5, 2120–2131.

60 Gaysinsky, S., Taylor, T.M., Davidson, P.M., *et al.* (2007) Antimicrobial efficacy of eugenol microemulsions in milk against *Listeria monocytogenes* and *Escherichia coli* O157:H7. *J. Food Prot.* 70, 2631–2637.

61 Rattanachaikunsopon, P. and Phurnkhachorn, P. (2010) Assessment of factors influencing antimicrobial activity of carvacrol and cymene against *Vibrio cholerae* in food. *J. Biosci. Bioengr.* 110, 614–619.

62 Gaysinsky, S., Davidson, P.M., Bruce, B.D. and Weiss, J. (2005) Growth inhibition of *Escherichia coli* O157:H7 and *Listeria monocytogenes* by carvacrol and eugenol encapsulated in surfactant micelles. *J. Food Prot.* 68, 2559–2566.

63 Gaysinsky, S., Davidson, P.M., Bruce, B.D. and Weiss, J. (2005) Stability and antimicrobial efficiency of eugenol encapsulated in surfactant micelles as affected by temperature and pH. *J. Food Prot.* 68, 1359–1366.

64 Taylor T.M., Davidson, P.M., Bruce, B.D. and Weiss, J. (2005) Liposomal nanocapsules in food science and agriculture. *Crit. Rev. Food Sci. and Nutr.* 45, 587–605.

65 Hill, L.E., Taylor, T.M. and Gomes, C. (2013) Antimicrobial efficacy of poly (DL-lactide-co-glycolide) (PLGA) nanoparticles with entrapped cinnamon bark extract against *Listeria monocytogenes* and *Salmonella* Typhimurium. *J. Food Sci.* 78, N626–N632.

66 Hawkins, S. (2016) Combinations of multiple natural antimicrobials with different mechanisms as an approach to control *Listeria monocytogenes*. MS Thesis, University of Tennessee, Knoxville.

67 Nguefack, J., Tamgue, O., Dongmo, J.L. *et al.* (2012) Synergistic action between fractions of essential oils from *Cymbopogon citratus*, *Ocimum gratissimum* and *Thymus vulgaris* against *Penicillium expansum*. *Food Control*, 23, 377–383.

68 Reyes-Jurado, F., López-Malo, A. and Palou, E. (2016) Antimicrobial activity of individual and combined essential oils against foodborne pathogenic bacteria. *J. Food Prot.* 79, 309–315.

11

Antimicrobial Resistance in Food-Related Bacteria

Fengqin Li[1] *and Seamus Fanning*[2]

[1] *China National Centre for Food Safety Risk Assessment, Beijing, China*
[2] *University College Dublin, Dublin, Ireland*

11.1 Introduction

In recent years, arising from an over-reliance on antimicrobial compounds, in particular the third-generation cephalosporins (3-GC), bacteria have now become resistant, thereby reducing the chemothotherpaeutic value of these agents and compromising therapy. The emergence of a growing number of new antimicrobial-resistant and even multi-drug resistant (MDR) bacteria has become an increasing concern worldwide. Emergence of MDR isolates of food-borne origin, including *Salmonella* species, *Escherichia coli*, and *Campylobacter* species has reduced the efficacy of these antimicrobial compounds when used to control infections. Multi-drug resistant *Salmonella enterica* serovar Typhimurium DT104 have been prevalent in the UK, the US, and Germany since the 1980s. From 1997 to 1998, 703 (25%) of 2767 *Salmonella* isolates received at the National Antimicrobial Resistance Monitoring System (NARMS) in the US were identified as *S.* Typhimurium, and 259 (37%) of these were identified as DT104 by phage typing [1]. During 2005–2010, the Canadian Integrated Program for Antimicrobial Resistance Surveillance (CIPARS) identified increased prevalence of ciprofloxacin resistance among *Campylobacter* isolates cultured from retail chicken in British Columbia (4–17%) and Saskatchewan (6–11%), Canada [2]. An increase in the rate of resistance was also recorded in *Campylobacter jejuni* for fluoroquinolones (from 1 to 82%) and tetracycline (from 23 to 72%) and in *Salmonella* for ampicillin (from 8 to 44%), chloramphenicol (from 1.7 to 26%), and trimethoprim-sulfamethoxazole. Multidrug resistance was also detected in several *Salmonella* serovars [3]. In 1998, an estimated 5000 individuals in the US were infected following the consumption of poultry contaminated with *Campylobacter* species resistant to fluoroquinolone antimicrobial compounds [4]. Not surprisingly, these isolates did not respond to treatment with compounds in this drug class.

In light of the relationship between the emergence of drug-resistant bacteria originating in food-producing animal origin coupled with the use of antimicrobial compounds in animal feeds, the EU and the US now implement strict control measures. Furthermore, efforts to reduce the use of specific drug classes in animal feeds are also being made.

Food Safety in China: Science, Technology, Management and Regulation, First Edition.
Edited by Joseph J. Jen and Junshi Chen.

Countries around the world have now begun to re-direct their research focus from one that explores the nature of drug resistance, induced by low-dosage use, in food-producing animals, to one that explores the nature of how the antimicrobial resistance develops and spreads, an important issue of concern to public health. From the food safety perspective, this includes studying the prevalence of zoonotic pathogens based on comprehensive monitoring, and exploring how drug resistance occurs and becomes disseminated, all of which contribute towards the development of scientifically sound preventive and control strategies, thereby strengthening the response capacity to deal with emergencies, whenever they arise.

NARMS jointly launched by the US Food and Drug Administration (FDA), the Centers for Disease Control and Prevention (CDC), and the US Department of Agriculture (USDA) in 1996 aims to describe the trends in antimicrobial resistance transmission for *Salmonella* isolates cultured from animals, food, and humans along with other food-borne enteric bacteria. This program works to facilitate the identification on a timely basis of resistance phenotypes among bacterial isolates cultured from food-producing animals and humans; it also seeks to promote good manufacturing practices through the monitoring of patent expiry dates. Similarly, the EU established a regional surveillance network Enter-Net in the 1990s and along with the World Health Organisation (WHO) Global Salm-Serv (GSS) platform, it acts as a global surveillance network to monitor isolates of this genus, cultured from food-producing animals and foods around the world, and it particularly focuses on those that are proven to be phenotypically drug resistance. The WHO Global Principles for the Containment of Antimicrobial Resistance in Animals Intended for Food (currently at the drafting stage of development) developed in collaboration between the WHO, the United Nations Food and Agriculture Organisation (UN-FAO) and the World Organisation for Animal Health (OIE) in 2000 aims to monitor the use of antibiotics/antimicrobial compounds in food-producing animals and to investigate the relationship between their use in these animals and resistant bacteria cultured from humans, so as to effectively control and limit the development and subsequent transmission of drug resistance. Bacteria cultured from various sources, including humans, animals, and foods of animal origin are normally tested for susceptibility to 17 antimicrobial compounds, in order to explore the link between the use of animal antimicrobial compounds and drug resistance in human pathogens. Data obtained suggest that 12% of *Salmonella* isolates from the human clinical samples in 2000 were resistant to at least five antimicrobial agents, including ampicillin, chloramphenicol, streptomycin, sulfamethoxazole, and tetracycline. In China, the extensive use and in particular the abuse or irrational use of antimicrobials and antiparasitic drugs in veterinary medicine and animal breeding programs has led to increased drug resistance being detected among bacteria and parasites alike, cultured from these sources. The major food-borne pathogens, including *Staphylococcus aureus*, *E. coli*, and *Salmonella* species, now express resistance to several antimicrobial compounds, with some isolates being classified as MDR. Over the last 70 years of antibiotic production and use, allied to the extensive use of these agents in animal breeding, aquaculture, and medical care, it is not surprising that drug-resistant bacteria are being identified and are also being widely transmitted. Furthermore, antibiotic resistance mechanisms are recognized that are now increasingly complicated, with bacteria evolving from single-drug resistant- to MDR-phenotypes and even to superbugs expressing a pan-drug-resistant phenotype.

The extensive use of antimicrobial compounds provides the conditions for selection, spread, and persistence of resistant bacteria. Importantly, resistance genes are transferred among bacteria of different genera. These may emerge initially as a locally based event, but following subsequent adaptation, can expand *via* transmission routes including the food chain. These features can in turn lead to an increase in the global prevalence of infectious diseases affecting the human population, many of which may be untreatable with compounds in the current antimicrobial arsenal. Further, it is recognized that when bacteria become resistant, this can lead to increases in morbidity and mortality, often arising due to the enhanced virulence phenotype expressed. For instance, 24 patients in intensive care units at Tisch Hospital, New York, became infected or were colonized by a carbapenem-resistant *Klebsiella pneumonia* over a one-year period. Eight of these individuals died, and the subsequent follow up identified the bacterial infection as the contributory cause. In this case, these isolates were broadly resistant to compounds in a number of antibiotic classes, and consequently the chemotherapeutic approach to treatment failed [5]. When compared to infections with susceptible *K. pneumonia,* in this example there was a three-fold increase in mortality [6,7]. The health-economic impact of increasing numbers of these untreatable infectious diseases can be expected to become significant in time. As an example of this, a cost comparison of treating methicillin resistant *S. aureus* (MRSA) *versus* methicillin sensitive *S. aureus* (MSSA) in New York City reported a three-fold increase in mortality (21% *versus* 8%) together with an economic cost increase of 22% associated with MRSA. For all hospitalized individuals with MRSA in New York City, such costs would translate into millions of dollars [8]. In a separate study, it was estimated that the health-economic costs would run to US $150 million to $30 billion per year, depending on the number of deaths [9]. Hence, antimicrobial resistance is likely to be a permanent feature of human society, leading to increased human suffering and attendant social costs.

Our world is now entering a *post-antibiotics* era where the existing arsenal of antibiotics/antimicrobial compounds will be ineffective to treat common infections. In 2011, the WHO coined the phrase, “No Action Today, No Cure Tomorrow” to highlight the deteriorating situation and to seek a response. In this review, the authors provide a broad overview of antimicrobial resistance related to food-borne pathogens and probiotics used in the modern food industry in China.

11.2 *Salmonella* Species

Salmonella species remain a global challenge and these bacteria are recognized as important food-borne pathogens. It is estimated that *Salmonella* is linked to 93.8 million cases of gastroenteritis, and 155,000 deaths globally are caused by *Salmonella.* In the US, food-borne salmonellosis accounts for 11% and ranks second among all food-borne diseases reported. The CDC annually receives approximately 40,000 laboratory-confirmed salmonellosis cases, of which 96% are attributed to a food source [10]. In China, food poisoning caused by *Salmonella* has been ranked in first place, with 75% of food-borne diseases caused by this bacterium. Specifically, the majority of the infections originate from animal sources, with *Salmonella*-contaminated chicken products being attributed as the major cause of human food poisoning. Some 40% of the 2203 food-borne disease outbreaks reported from 2006 to 2010 in China were caused by microorganisms, while 70 to 80% of outbreaks with a defined etiology are attributed to *Salmonella* species (data not published). Thus, *Salmonella* infections have become an important public health issue in China.

Although most of the *Salmonella* infections do not require antibiotic therapy, invasive infections can be life-threatening, especially in immune-compromised cases, including children and the elderly. Third-generation cephalosporins (3-GC) and ciprofloxacin are the first-line drugs of choice for treating *Salmonella* infections. However, *Salmonella* isolates that are resistant to fluoroquinolones (FQ) or 3-GC are now being regularly reported. Recently in China, the emergence of a *Salmonella* Indiana isolate that was found to be co-resistant to 3-GC and ciprofloxacin, has been reported. Early research findings indicate that a large number of these isolates are linked to contaminated chicken samples collected from bird farms and slaughterhouses. Chinese researchers have also identified the same resistant *Salmonella* isolate in pork [11].

China is the global leader in animal breeding with a heavy reliance on the use of antibiotics, which are authorized as veterinary drugs for the treatment of animal disease, as well as a growth promoter. However, antibiotic use and its management as applied to animal breeding is not standardized in China, compared with similar programs in developed countries. As microorganisms in the animal production environment and in the animal themselves are abundant, it is not surprising that when resistance to antimicrobial compounds first appears it is amplified in commensal bacteria, being subsequently transmitted horizontally *via* a number of mobile genetic elements (MGE) including conjugative plasmids, bacteriophages, and in some cases by natural transformation. Genes encoding these resistance mechanisms may in time reach pathogenic bacteria. These events pose a threat to public health due to the fact that they are transmitted to humans *via* the food chain, thereby increasing the risk of therapeutic failure. Wang Juan *et al.*[12] reported on the susceptibility of *Salmonella* isolates from five poultry farms in Shandong, Henan, and Anhui provinces and showed that with the exception of ceftiofur to which less than half of the 24 *Salmonella* isolates were resistant, many of the isolates in this collection were resistant to 13 other antimicrobial compounds tested. In particular, all of these isolates were resistant to ampicillin, difloxacin, enrofloxacin, sulfamethoxazole, sulfisoxazole, and tetracycline. Those isolates expressing a multi-drug resistant isolates (MDR, defined as being resistant to three or more different classes of compound) phenotype included 12.5%, 29.2%, 45.8%, and 12.5% of this collection and these were found to be resistant to 10, 11, 12, and 14 antimicrobial compounds, respectively. In a study reported by Pan Zhiming *et. al.* [13], 346 *Salmonella* Pullorum cultured from different regions of China between 1962 and 1999 were studied. Based on these data, MDR *Salmonella* isolates increased in number over the 40-year study period. The isolates of particular interest in this study were those that were originally found to be resistant to two antimicrobial compounds during the 1960s, after which their resistance increased to four and five agents by the 1970s, then to five and six drugs in the 1980s and in the 1990s more than 83.7% of these isolates were found to be resistant to seven or more antimicrobial drugs. Susceptibility testing conducted on 231 *Salmonella* isolates cultured from food matrices in 2003 showed that 62.8% of these were resistant; 37.2% of the study collection in this case was resistant to more than three antimicrobial compounds and all were resistant to one or more drugs. Of the resistant isolates identified, many expressed phenotypic resistance to older compounds such as amoxicillin, nalidixic acid, streptomycin, sulfonamides, and tetracycline, with the greatest proportions, 41.6% and 33% found to be resistant to nalidixic acid and tetracycline, respectively. In 2004, another study reported on the antimicrobial resistance profiles of 52 food-related *Salmonella* isolates from eight provinces in China, and 51 of these were resistant to more than three antimicrobial compounds, with 15.7% being resistant to only three agents. Thirteen isolates (25.5%) were found to be resistant to four compounds, nine isolates (17.6%) to five antimicrobial agents, 12 isolates or 23.5% were resistant to six and up to nine compounds, with a final nine isolates expressing resistance to more than 10 agents. As these resistant isolates were cultured from retail chicken, available for sale in the local market, these findings suggest a lack of proper oversight when using antimicrobial compounds for animal production, an observation that demands urgent action to protect public health.

The susceptibility testing and analysis for 563 *Salmonella* isolates from 16 provinces in 2005 detected 273 resistant *Salmonella*. Among these, 167 or 29.7% were resistant to more than three antimicrobial compounds; 26 isolates or 9.5% were resistant to more than ten agents. Among the common compounds to which resistance was detected, resistance to tetracycline was common at 36.8%, followed by 29.3% to doxycycline, 24.7% to nalidixic acid, 19.5% to sulfonamide isoxazolyl, 15.6% to ampicillin, 11.7% to cotrimoxazole, 11.2% to nitrofurantoin, and 11% to chloramphenicol, a compound whose use is banned in animal production.

Susceptibility testing and subsequent genetic analysis of a collection of 2647 *Salmonella* cultured from the whole chicken carcass for domestic sale in the local markets in six provinces was reported by Hu Yujie *et al.* in 2015 [14]. The authors identified 227 *Salmonella* isolates that were found to be co-resistant to ceftazidime/cefotaxime and ciprofloxacin. Serotyping identified 224 of the 227 co-resistant *Salmonella* to belong to the serovar Indiana, with 213 or 95.10% of these expressing resistance to extended-spectrum β-lactams (ESBLs). All of the co-resistant *Salmonella* were found to be resistant to more than five antimicrobial compounds, with 17.86% of the ciprofloxacin and cefotaxime co-resistant *Salmonella* isolates (40/224) being resistant to ten compounds, and 50.89% of the collection being resistant to nine agents. The predominant antimicrobial resistance profiles identified in this study included ciprofloxacin-cefotaxime-nalidixic acid-ampicillin-gentamicin-chloramphenicol-tetracycline-ampicillin/sulbactam-trimethoprim/ sulfamethoxazole (88/224 or 39.28%). Some 25.45% (57 of the 224) of the co-resistant *Salmonella* Indiana isolates were resistant to eight antibiotics, with the predominant resistance profile as ciprofloxacin-cefotaxime-nalidixic acid-ampicillin-gentamicin-chloramphenicol-ampicillin/sulbactam-trimethoprim/sulfamethoxazole (23/224 or 10.27%). Interestingly, none of these isolates were resistant to carbapenems.

Based on these findings, retail whole chicken carcasses in China appear to be contaminated by *Salmonella* that has been found to be resistant to both ciprofloxacin and cefotaxime, and therefore this food source can be regarded as an important reservoir. The same strain type has been reported globally and once it is detected in hospitals it can be disseminated to the community by various means, thereby compromising public health.

Quinolone-resistance determining regions (QRDRs) and plasmid-mediated quinolone resistance (PMQR) also play an important role in the resistance mechanisms against compounds in the FQ class. Target gene mutations in *gyrA* and *parC*, which encode subunits of DNA gyrase and topoisomerase IV, respectively, contribute to resistance among *Salmonella* isolates. PMQR mechanisms include Qnr proteins that function to protect the drug target, the bi-functional *aac (6')-Ib-cr* enzyme and the

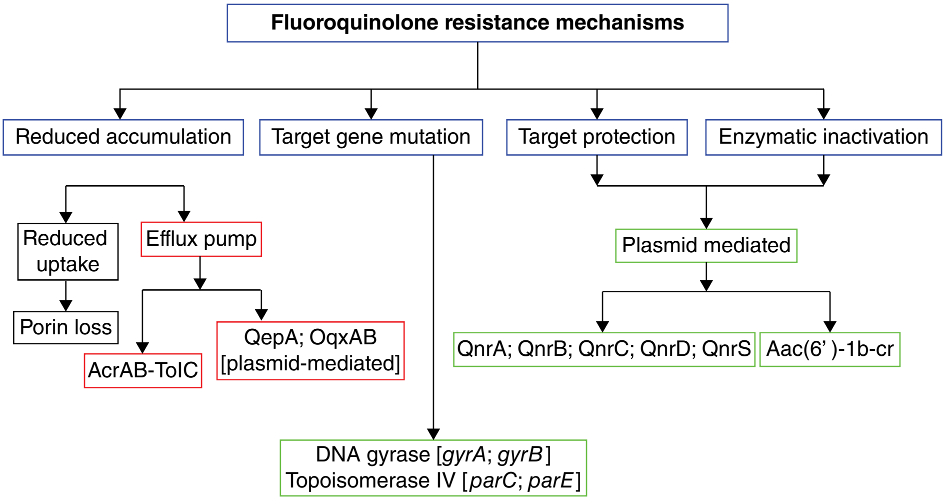


Figure 11.1 Mechanisms of *Salmonella* resistance to fluoroquinolones.

specific efflux transporters encoded by *qepA* and *oqxAB*. All of these function to reduce the susceptibility of *Salmonella* isolates to FQ compounds (Figure 11.1).

Since the isolation of SHV-2 ESBLs first reported in Germany in 1983, new variants have been documented in several countries, with the majority of these resistance mechanisms being mediated by plasmids. The latter feature has ensured that ESBLs can spread rapidly among members of the *Enterobacteriaceae, via* horizontal transmission mechanisms, and this has occurred between bacteria of the same genus and across species. The main genotypes associated with *Salmonella* that express ESBL-based resistance in Asia contain CTX-M-type enzymes. To assess the extent to which *Salmonella* co-resistant to 3-GC and ciprofloxacin are linked to contaminated foods of animal origin in China, the China National Centre for Food Safety Risk Assessment (CFSA) carried out a surveillance program to establish the extent of this resistance among samples taken from commercial pig and poultry units [15]. These data showed that 57.1% and 39.8% of 198 *Salmonella* isolates (including 128 from pigs and 70 from chickens) were resistant to more than three antimicrobial compounds, a finding that was generally higher when compared with other countries. Of note, 11 *Salmonella* Indiana isolates were classified as being *super-resistant*, due to the fact that they expressed high levels of resistance to both 3-GC and ciprofloxacin, the first-line drugs used in clinical settings to treat salmonellosis. Further studies focusing on the corresponding resistance mechanisms identified both plasmid-mediated determinants (including *aac (6')-Ib-cr* and *oqxAB*) along with target gene mutations in the chromosome (including *gyrA* and *parC*). In this case, it is tempting to speculate that the unrestricted use of agents of both of these antimicrobial classes may have contributed uniquely to the emergence of these multi-faceted resistance mechanisms, in these Indiana serovars. When the nature of the ESBL genotype was investigated, a plasmid encoding a 3-GC resistant gene, $bla_{\text{CTX-}M\text{-65}}$ was identified. Furthermore, the existence of this genotype in *Escherichia coli* highlights the fact that the potential exists for dissemination of this marker. This development may be somewhat unique given the clustering of these co-resistant *Salmonella* Indiana isolates, a feature that challenges approaches to the clinical treatment of individuals infected with this serovar.

The increasingly intensive nature of industrialized poultry production and subsequent processing, along with the rapid growth of regional tourism in China have increased opportunities that could contribute to the emergence of *super-resistance* bacteria of importance to human health. Furthermore, the association of some of these genes with plasmids capable of high frequency transmission into and throughout different ecological niches, including animals, humans, various food matrices, and the broader environment, has added to this public health challenge. As a first step in attempting to control and reduce the risk to human health, it is necessary to undertake a detailed molecular epidemiological study to identify possible sources from which the dissemination of these MGEs can be followed. These data would form the basis upon which a focused risk assessment could be made and control options developed.

11.3 *Escherichia coli*

This bacterium is a well-known commesal microorganism found in the intestines of humans and animals. *Escherichia coli* (*E. coli*) can contaminate water, soil, and food *via* feces or during animal slaughtering. Several multi-drug resistant *E. coli* have emerged in recent times, expressing resistance to WHO-listed critically important antimicrobial compounds. Examples include the metallo-β-lactamase NDM-1 (New Delhi metallo-β-lactamase-1) and the transmissible colistin-resistance mechanism elaborated by MCR-1. It is thought that these mechanisms of resistance emerged as a result of the extensive use of antimicrobial compounds in animal production, as well as in aquaculture. Together with the increased reporting of resistant *E. coli* from human sources, food contaminated with these organisms, originating from food-producing animals, and cross-contamination arising during processing has become an important food safety issue. More than 70% of *E. coli* cultured from foods in China are resistant to penicillin, with greater than half of these isolates being co-resistant to fluoroquinolones. Some 70% of *E. coli* isolates were classified as multi-drug resistant, with 10% of these being resistant to ciprofloxacin [16]. Mechanisms underpinning the latter included mutations in target genes (associated with QRDRs) along with PMQR, both playing an important role in this mechanism. Mutations were commonly identified in four to five loci on the bacterial chromosomes, these being typically mapped to the *gyrA*, *parC,* and *parE* encoding genes. Compared with isolates in other countries, *E. coli* isolates identified in China have also been known to carry resistance elements to different PMQRs including *qnr*-encoding determinants, *aac (6')-Ib-cr*, *qepA*, and *oqxAB.*

Resistance to ESBLs in this bacterial genus is also of importance to public health. In this case the corresponding genes are transmitted *via* plasmids and this feature serves as a major route by which to disseminate resistance to β-lactam antibiotics. Extended-spectrum β-lactamase (ESBL)-producing bacteria have become an important resistance reservoir in the hospital and community through acquired infections. Thus research focusing on *E. coli* that are ESBL-positive is relevant to protect public health. According to the Lahy Database (http://www.lahey.org/Studies/), more than 1000 enzymatic variants have been identified among ESBL-producing bacteria from different genera. As of 5 May 2016, the database contained 223 TEM types, 148 CTX-M types, 193 SHV types, and 365 OXA types, with an increasing number of other variants such as PER, VIM, VEB, LEN, KPC, OKP, and GES. The global spread of plasmid-mediated multi-drug resistance and virulent factors have posed increased threats to the successful treatment of bacterial infections in human and animals. Clinically, TEM, SHV, and CTX-M represent the major genotypes associated with ESBL-positive phenotypes, subtypes encoded by $bla_{\text{CTX-M-1}}$, $bla_{\text{CTX-M-14}}$, $bla_{\text{CTX-M-52}}$, and $bla_{\text{SHV-12}}$ account for the majority of these genotypes identified from animal sources. ESBL-producing *E. coli* reported from China and elsewhere were mainly cultured from patients and food-producing animal breeding farms. In China, around 10% of the *E. coli* cultured from food sources were found to be ESBL-positive with $bla_{\text{CTX-M-14}}$, $bla_{\text{CTX-M-15}}$, $bla_{\text{CTX-M-65}}$, and $\text{bla}_{\text{CTX-M-79}}$ being the main genotypes identified.[17]

The emergence of MDR *E. coli* isolates carrying mobile genetic elements containing carbapenemase-resistance mechanisms, such as KPC-2 (*Klebsiella pneumoniae* carbapenemase-2) and NDM-1, have been reported. Use of such antibiotics in clinical medicine is restricted and these compounds are not indicated for veterinary use. However, both types of resistant *E. coli* have been isolated from clinical specimens and food-producing animal breeding farms in China. Similar isolates have not been reported in food sources to date. Clinically, carbapenemase-resistant Enterobacteriaceae are treated with polymyxin or tigecycline, and both of these drugs are regarded as the last line of defense for the treatment of complicated bacterial infections. Specifically, polymyxin B and polymyxin E (colistin) are often administered clinically and used in the treatment of ESBL-positive Enterobacteriaceae. These drugs target the lipopolysaccharide (LPS) structure located in the outer membrane of Gram-negative bacteria. Until very recently, the mechanism of resistance to colistin was thought to involve chromosomally mediated gene mutations that specifically targeted two-component regulatory systems such as *pmrAB* and *phoPQ.* Other targets recognized include the small RNA-encoding gene *mgrB,* that functions to negatively regulate the expression of a *eptB*-encoding a phosphatidylethanolamine transferease. Mutations in these chromosomal genes result in cellular changes that reduce the affinity of these cationic peptides for the bacterial cell. Due to their location, such mechanisms were thought to be non-transferrable.

Polymyxin has always been used as a veterinary drug in the animal breeding industry. Recently Professor Liu Jianhua from the South China Agricultural University and Professor Shen Jianzhong from China Agricultural University reported a novel colistin encoding-resistant gene denoted as *mcr-1* that was carried on a transmissible IncHI2 plasmid in isolates of *E. coli* cultured from food-producing animals and hospitalized patients.[18] These authors reported that *mcr-1* mainly existed in China and was likely to have spread to Southeast Asia. Since its publication, researchers from the China Academy of Sciences conducted a comparative genome analysis on 31,000 bacterial genomes, 4500 meta genomes, and 9.8 million human intestinal bacterial genes (1267 human samples from China, the US, and Europe) in an effort to identify this determinant. Results showed that *mcr-1* was transmitted to intestinal bacteria in healthy Chinese people and this gene can also be found in Europe, before 2011. Similarly, the *mcr-1* gene was detected in bacteria cultured from chicken, pigs, and other food-producing animals, along with retail meat. These findings highlight the transmissible nature of this gene and once again focus the attention of public health professionals on the importance of monitoring resistance mechanisms in bacteria of relevance to food safety [19,20].

11.4 Staphylococcus aureus

Staphylococcus aureus is a recognized food-borne pathogen. In recent years, as a result of the over-use of various antimicrobial compounds, in particular the 3-GCs, a growing number of drug-resistant *S. aureus* have emerged and been found to contaminate food by a variety of means.

The current literature reports levels of antimicrobial resistance among food-borne *S. aureus* cultured from a variety of food matrices, including raw and processed meats, rice and flour products, dairy products, soy bean products, salad, and cold dishes in some regions of China. These isolates were found to be resistant to first- and second-line clinical antimicrobial compounds, including chloramphenicol, clindamycin, erythromycin, penicillin, and tetracycline (with resistance frequencies from 20% to 100% being recorded). Susceptibility has been reported for third-line clinical compounds such as glycopeptides (including vancomycin) and oxazolidines (linezolid) along with varying degrees of resistance to aminoglycosides, cephalosporins, fluproquinolones, and sulfonamides [21,22]. In a study carried out by Fan Qin *et al.* in 2015,[18] *S. aureus* cultured from milk between 2006 to 2011 were recovered and these isolates had their susceptibility tested against a panel of 10 antimicrobial compounds. High numbers of these isolates were found to be resistant to ampicillin and penicillin, as well as to amoxicillin/clavulanic acid, erythromycin, and trimethoprim/sulfamethoxazole. Interestingly, these same isolates remained susceptible to oxacillin and ceftiofur [23]. Some 72.1% to 100.0% of the study isolates exhibited a multi-drug resistance phenotype. In a 2013 study, reported by Zhao Xiulong *et al.*, 29 *S. aureus* cultured from 30 milk samples taken from six dairy farms in Qingdao expressed high levels of resistance to various antibiotics, including penicillin (72.41%), streptomycin (68.97%), kanamycin (62.07%), neomycin (58.62%), and gentamicin (58.62%) [24].

In a study of 602 food-related *S. aureus* tested against a panel of 13 antimicrobial compounds in 2014, all were found to be susceptible to linezolid, daptomycin, and vancomycin; 572 isolates from the 602 were resistant, with 85.7% (516/602) being resistant to penicillin, 65.4%(394/602) to erythromycin, and 49.7% (299/602) were found to be resistant to chloramphenicol, followed by 2.6% (196/602) that were resistant to tetracycline, 28.7% (173/602) to clindamycin, and 14.8% (89/602) were resistant to gentamicin. MDR accounted for 52.3% of the total collection (data not published).

When re-analyzed by food category, all of the *S. aureus* isolates from raw meat and Chinese salad were found to be resistant; and this was particularly notable among those isolates cultured from rice- and wheat-flour-based products, processed meat products, and boxed cooked rice. In these cases, resistant isolates accounted for 98.0%, 95.0%, and 83.3% of the total collection.

In another study MDR *S. aureus* cultured from raw meat origins accounted for 77.42% of the collection, with isolates from rice and flour products, raw meat, and Chinese salad making up over half of the study collection, and boxed cooked rice positive samples accounting for 36.67% [20]. These values support the findings of other authors reported in the literature, which suggest that MDR *S. aureus* isolates are a frequent occurrence in China; high levels of resistance are prevalent in raw and processed meats, and multi-drug resistant *S. aureus* can be detected in rice- and flour-based products, as well as Chinese salad.

Of interest, MRSA was detected recently in foods in China. A study of 124 *S. aureus* cultured from 1200 processed food matrices, including meat, soy bean products, salad, fresh juice, and milk samples was reported by Zhuge *et al.* [25]. In contrast to MSSA, which is highly resistant to a small number of antibiotics such as erythromycin, penicillin, and tetracycline, and, with the exception of vancomycin, MRSA exhibited high resistance rates of between 64.29% to 100% to other compounds, including cefotaxime, cefazolin, ciprofloxacin, gentamicin, oxacillin, rifampicin, and sulfamethoxazole [26]. According to the susceptibility testing of 23 food-borne MRSA collected by the China National Contaminant Surveillance Network and assessed against a panel of 16 antimicrobial compounds, all were susceptible to linezolid, vancomycin, tigecycline, and nitrofurantoin, but were resistant to ampicillin, cefoxitin, and oxacillin, with multi-drug resistance being recorded in 95% of these isolates [27]. Although no MRSA were identified that were resistant to vancomycin this drug can be used for animal remedies, but only with caution and under veterinary supervision.

11.5 *Campylobacter* species

Campylobacter species can be transmitted to humans *via* contaminated food or water. This bacterium causes 400 to 500 million food-borne cases each year [28]. In developed countries such as Denmark, New Zealand, Sweden, and the UK, *Campylobacter* infections increased by a factor of 10 to 50 per year between 1980 and 1998 [29]. In Europe some 190 000 food-borne cases have been recorded annually between 2006 and 2011 and their prevalence continues to increase. A total of 200 million *Campylobacter* infection cases occur each year in the US, of which 15% require hospitalization.

Campylobacter species are the most commonly detected bacterial etiological agent in cases of infectious diarrhea among infants and young children in the developing world, being isolated from 8%–45% of the fecal samples taken from children presenting with diarrhea in some African and Asian developing countries [30–32]. Foods of animal origin, in particular poultry, are an important vehicle for human infections, with consumption of contaminated chicken being closely associated with the prevalence of campylobacterosis. In China, multiple food-borne *Campylobacter* infections occurred in Shanghai, Beijing, and Fujian, following surveys of *Campylobacter* contamination in foods, and this bacterium has been reported in clinical laboratories [33].

In many countries, human infections caused by *Campylobacter* have exceeded those caused by *Salmonella* species and *E. coli*. Fluoroquinolone and macrolide antimicrobial classes are the compounds of choice to treat campylobacteriosis. Aminoglycosides can be used as an alternative treatment in cases of systemic infections caused by this bacterium. The emergence of *Campylobacter* isolates that are resistant to commonly used clinical drugs along with the increased resistance has rendered these antimicrobial agents ineffective for treatment. Research has shown that *Campylobacter* isolates from different sources and regions demonstrated a degree of variation in their susceptibility profiles. As the empirical drug class used for the treatment of enteric bacterial infections, resistance to fluoroquinolones has been reported in several countries, with levels in some countries as high as 90% [34–38].

Macrolides are the front-line drug class clinically recommended for the treatment of clinical *Campylobacter* infections, and erythromycin is the drug of choice due to its safety record, minimal side effects, easy management, and cost-effectiveness. In contrast, newer macrolides such as azithromycin and clarithromycin are more expensive, despite achieving better responses to *Campylobacter* infections. In recent years, *Campylobacter* resistance to macrolides has been frequently reported and this reduced efficacy has become an important public health issue. With *Campylobacter* resistance to macrolides being prevalent globally, some countries, such as member states within the EU and the US, where availability of these antibiotics is strictly managed, report a low prevalence of resistant *Campylobacter* strains, while resistance is growing in countries where control of antibiotics use is comparatively lax.

Food-borne *Campylocbater* isolates generally show high levels of resistance to macrolides in China, while the resistance among clinical isolates from different regions varies significantly, ranging from susceptibility to resistance at 62.5%, with low macrolide resistance being recorded in developed countries. In parts of China, *C. coli* cultured from chicken feces were found to be highly resistant to erythromycin, as a possible consequence misuse of this compound [39]. In a study carried out by Baiyao *et al.*, *Campylobacter* isolated from whole chicken carcasses (n = 240) collected from the retail markets of Beijing were tested for their susceptibility to a number of antimicrobial compounds. Results indicated that 21 antimicrobial resistance profiles could be identified among 151 *Campylobacter* isolates studied, including 20 profiles among 85 *C. jejuni* and 10 profiles for 66 *C. coli*, respectively. The antimicrobial resistant profiles differed between *C. jejuni* and *C. coli*. Multi-drug resistant profiles were observed in 33 (39.2%) *C. jejuni* (cultured from 27 chicken carcasses) and 57 (86.4%) *C. coli* (from 30 chicken carcasses). The most common antimicrobial resistance profiles of 85 *C. jejuni* isolates were ciprofloxacin-doxycycline-tetracycline (n = 19, 22.4%), ciprofloxacin-tetracycline (n = 12, 14.1%), chloramphenicol-ciprofloxacin-tetracycline (n = 8, 9.4%), and chloramphenicol-ciprofloxacin-gentamicin (n = 6, 7.1%). Similarly, the most common antimicrobial resistance profiles among 66 *C. coli* were azithromycin-chloramphenicol-ciprofloxacin-gentamicin-doxycycline-erythromycin-tetracycline (n = 23, 34.8%), azithromycin-ciprofloxacin-tetracycline-gentamicin-doxycycline-erythromycin (n = 14, 21.2%), and azithromycin-gentamicin-doxycycline-erythromycin-tetracycline (n = 10, 15.2%) [40]. Figure 11.2 shows the multi-locus sequence typing of *Campylobacter* from chicken.

11.6 Listeria monocytogenes

Infections wherein *Listeria monocytogenes* is the etiological agent can present clinically with sepsis, meningitis, and mononucleosis. These microorganisms are psychotropic, being capable of growth at 4 °C. This bacterium can infect humans *via* contaminated milk and dairy products, vegetables, and aquatic and meat products, and is the major pathogenic bacterium of concern to public health in frozen food. Antibiotic treatment may be required for *L. monocytogenes* infections associated with cases following the consumption of contaminated food. In the past year, increased resistance has been detected in food-borne *L. monocytogenes* and this finding has focused attention on the potential risks associated with food safety. Ampicillin is a front-line drug used for treatment when indicated, with co-trimoxazole being available as an alternative when

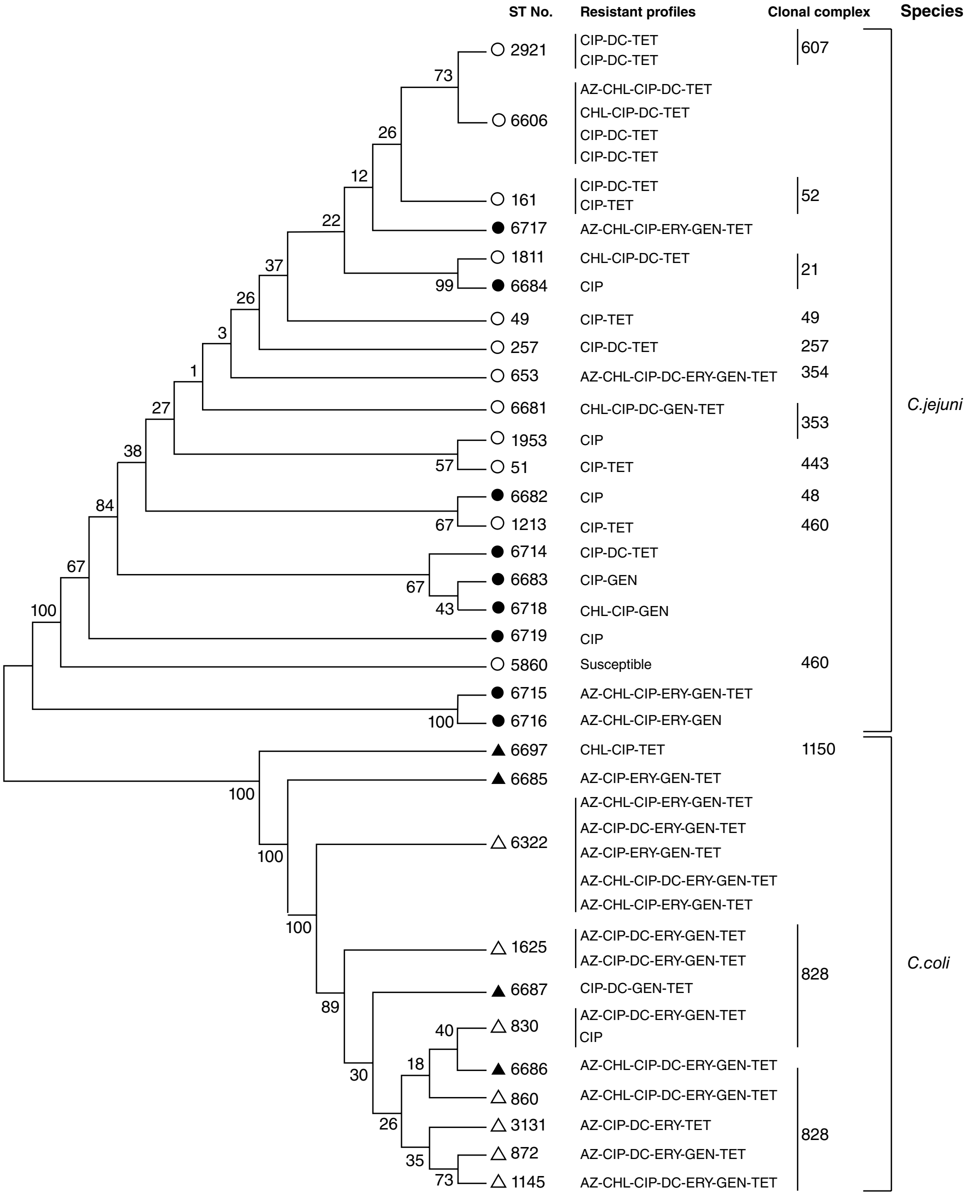


Figure 11.2 Multilocus sequence typing and the corresponding antimicrobial drug resistance profiles of *C. jejuni* and *C. coli* isolates (Circles indicate *C. jejuni*; triangles indicate *C. coli*).

resistant isolates are detected. *L. monocytogenes* is generally susceptible to both of these agents with only occasional reports of resistance appearing in the literature.

In China, according to the monitoring programmes carried out by the National Food Safety Risk Monitoring Network (NFSRMN), resistance among isolates of *L. monocytogenes* recorded from 2003 to 2014 was: 14.1% for 2003–2004, 4.5% for 2005, 8.66% for

2007, 5.96% for 2008, 6.53% for 2009, 10.39% for 2012, 21% for 2013, and 9.10% for 2014 (data not published). Despite the low levels of resistance, calculated at approximately 10% and with the exception of the 21% value recorded in 2013, the trend to increased single-drug resistance being observed over recent years should warrant closer scrutiny by regulatory agencies. Specifically, one isolate resistant to ampicillin was detected in 2012, with two more being detected in 2013. All isolates were susceptible to co-trimoxazole apart from 27 resistant isolates that were detected in 2014. At present, ampicillin remains a safe and effective chemotherapeutic option to treat *L. monocytogenes* infections; however, with the emergence of food-borne *L. monocytogenes* elaborating resistance to ampicillin and co-trimoxazole, greater caution should be exercised when empirical treatment is used for such infections. Notably, the isolates detected as resistant to tetracycline and ciprofloxacin accounted for the highest proportion at over 50%, with the ciprofloxacin-intermediate strains being dominant. Other antibiotics to which high levels of resistance were observed included chloramphenicol and erythromycin, while fewer isolates were found to be resistant to gentamicin and vancomycin.

Analysis of various food sources were found to be positive for *L. monocytogenes* isolates, including raw chicken, vegetables, cold dishes, and raw meat, and these isolates exhibited higher than average levels of resistance. *L. monocytogenes* cultured from prepared meats, boxed rice, hot dishes, and dairy products exhibited lower resistance, in contrast to those isolates cultured from raw pork, raw beef, aquatic products, and prepared meat. Geographically, the resistance levels in Henan and Shandong provinces, along with Inner Mongolia, exceeded 20%. Monitoring data from 2007 to 2009 suggested that Gansu, Jilin, Fujian, and Jiangsu provinces were mainly associated with resistant *L. monocytogenes*, while in 2012, resistant isolates were geographically concentrated mainly in three provinces: Shandong and Henan together with Inner Mongolia. As the main meat producing and processing provinces in China, all three are likely to become high-risk regions for the clustering of resistant *L. monocytogenes* and thus merit increased monitoring.

Data analysis has revealed a simple distribution of food-related *L. monocytogenes* resistance profiles in China. The NFSRMN network reported ten resistance profiles for each of the eight antimicrobial compounds, including ampicillin, chloramphenicol, ciprofloxacin, co-trimoxazole, erythromycin, gentamicin, tetracycline, and vancomycin, it was found that more than half of the isolates tested were resistant to a single drug. However, MDR *L. monocytogenes* were also present, with a high proportion of these being cultured from raw meat. It is tempting to speculate that this observation may initially reflect the use of antibiotics in the breeding of pigs and other food-producing animals. Resistant isolates of *L. monocytogenes* were detected in rice and flour products, and Chinese salad, and this finding is suggestive of substandard hygiene measures being applied during food production and processing in China.

Drug resistance levels of *L. monocytogenes* reported locally by the provinces vary significantly, but are similar to the information captured by the NFSRMN network. Local and national reports show data that are closely related in terms of the isolate resistance profile, and this was recorded as 20.93%, 11.63%, and 9.30% for the 43 strains resistant to chloramphenicol, co-trimoxazole, and ciprofloxacin, respectively, in Yangzhou's drug susceptibility test program in 2005 [41]. Interestingly, resistance to chloramphenicol was higher than the values recorded by the monitoring network and this can be attributed to a small sample size. Furthermore, resistance to tetracycline was high, as shown by both the local reports and the national monitoring network, with 15.4% of 91 strains exhibiting resistance in the period from 2005 to 2007.[42] The latter was also close to those figures reported from Shandong province and was similar to what was reported by the NFSRMN network. Of the panel of compounds tested, resistance to tetracycline was the highest. Such a level was close to that reported from Shandong province and was similar to that reported by the NFSRMN network. In particular, the resistance to tetracycline was the highest [43]. Also, 16.25% of the 80 *L. monocytogenes* isolates (13/80) cultured from raw and poultry meat, processed meat products, and aquatic products between 2009 to 2010, and cultured from samples taken in six cities, exhibited resistance. Specifically, the resistance to imipenem was greatest at 12.50% (10/80), which differed from the lower resistance levels previously reported from home and abroad [44].

11.7 *Enterococcus* species

As an important pathogen associated with hospital infections, *Enterococcus* species can be found on meat products, dairy products, and cold dishes [45–47]. This microorganism can withstand high salinity environments and heating, thereby facilitating its ability to proliferate in foods. *Enterococcus* species is a common cause for food poisoning in China. Dose-response studies showed that consuming foods contaminated with 10^5 CFU/g *Enterococcus* is sufficient to cause food poisoning in a healthy adult, and a lower number of microorganisms would be sufficient to infect infants, young children, and people with compromised immunity. Moreover, the bacterial cell wall thickness and the propensity to acquire resistant genes have contributed to its resistant phenotype to many antimicrobial compounds [48]. Furthermore, resistant genes carried by *Enterococcus* may also transfer to other food-borne pathogens and thus this bacterium can be regarded as a resistant gene reservoir for other commensal and pathogenic bacteria.

Arising from the view that *Enterococcus* is regarded as a commensal bacterium harmless to humans, the food safety issues caused by *Enterococcus* have long been over-looked and this feature has diverted attention, leading to a reduced monitoring of this microorganism in food. Based on available data, 55.77% of 52 dairy products, raw and processed meat products, vegetables, and mineral water samples obtained from a food market were found to be contaminated with *Enterococcus*, as reported by Wu Chenlu *et al.* [49]. In another report, Jiang Kan *et al.,* identified 22.6% of 164 batches of infant formula to be positive for *Enterococcus* species, with bacterial counts of between 0.36 and 110 MPN/g [50]. Some 57% of the 52 fresh retail pork samples from selected farmers' markets in Zhengzhou, Henan province were contaminated with *Enterococcus*. When tested, 60% to 86.7% of these isolates were resistant to doxycycline, erythromycin, kanamycin, and tetracycline, 13.3% to 33.3% of the study collection were found to be resistant to cefazolin, cefotaxime, ciprofloxacin, fosfomycin, norfloxacin, ofloxacin, rifampin, and penicillin, and 10.0% to 53.35% of the tested strains carried the following virulence genes: *aceAS*, *cylA*, *efaA*, *esp*, and *gelE* [51]. Li Bo reported that enterococci were the main putrefactive bacteria in fresh tofu stored for 24 h at 37 °C, with the contamination originating from the soy beans [52]. This laboratory reported that *Enterococcus* species were recovered from all floors, walls, waste water, and raw pork samples taken and analyzed from one large pork market in Beijing, and that 67.44%, 53.49%, 26.74%, 26.74%, 23.26%, and 20.93% of the recovered *Enterococcus* isolates were resistant to tetracycline, erythromycin, ciprofloxacin, high-concentration streptomycin, high-concentration gentamicin, and chloramphenicol. Furthermore 30 (34.88%) of these 86 isolates were resistant to more than three antimicrobial compounds. Interestingly, a fresh pork *Enterococcus* isolate was found to be resistant to daptomycin, a new agent and the first of the cyclo-lipopeptide antimicrobial class. The latter is regarded as the first alternative to vancomycin due to its unique antimicrobial mechanism and the fact that it is unlikely to lead to the development of resistance [53]. With such antibiotics introduced to the Chinese market in 2010, no daptomycin-resistant isolates have been reported from hospitals, nor from foods or food-producing animal breeding farms in China.

Other countries commenced surveillance programs for this microorganism, much earlier than in China, to describe the epidemiology of enterococcal contamination in food. *Enterococcus* species were recovered from 42.2% of the market fruit and vegetables tested in Spain, and out of the 17 *Enterococcus* isolates recovered, 29.41% were resistant to erythromycin, 5.89% to tetracycline, 11.76% to chloramphenicol, 35.29% to ciprofloxacin, 35.29% to levofloxacin, 11.76% to gentamicin, and 5.88% to streptomycin. One isolate was resistant to penicillin/ampicillin and vancomycin. Twenty-two *Enterococcus* isolates that were recovered exhibited resistance as follows: 13.63% to quinupristin/dalfopristin, 4.54% to ampicillin/penicillin, 45.45% to ciprofloxacin, 22.72% to levofloxacin, 63.63% to rifampicin, 4.54% to nitrofurantoin [53]. For the *Enterococcus* isolates recovered exhibiting resistance to 14 antimicrobial compounds, 2.95 resistance genes per isolate represents the average resistance genotype, whilst among the 12 virulence genes tested there were 4.23 genes per isolate on average. *Enterococcus* was recovered from 48.3% of the 60 meat and fermented meat products in a Canadian food market, with 89.6% of the isolates found to be resistant to clindamycin, 65.5% to tetracycline hydrochloride, 62% to tylosin, 45% to erythromycin, 17% to streptomycin/ neomycin, 10.3% to chloramphenicol, 10.3% to penicillin, 10.3% to ciprofloxacin, and 3.4% to gentamicin, and 58.6% of the recovered enterococcus strains exhibiting resistance to more than three classes of drug [53]. *Enterococcus* isolates were recovered from 23.6% of the cheese, salad, ham, and raw meat in an Italian market (representing 311 of 1315 samples tested), with 21.9% of these being resistant to high-concentration gentamicin and 60.6% to tetracycline, followed by 3.53% to vancomycin, 2.24% to teicoplanin, 0.32% to linezolid, and amoxicillin/clavulanate. In general, a higher proportion of food-related *E. faecalis* were found to be resistant to antimicrobial compounds compared with *E. faecium*.

Comparison of *Enterococcus* isolates from China cultured from contaminated food, along with their corresponding susceptibility data allow the following observations to be made: a greater proportion of *Enterococcus* isolates recovered from food were resistant to older classes of antimicrobial compound, including erythromycin and tetracycline in China; a smaller percentage of these were found to be resistant to newer agents such as vancomycin and linezolid, (possibly due to their late introduction into clinical use). Commonly used antimicrobial compounds for animal production, together with the protracted use of ciprofloxacin, erythromycin, streptomycin, and tetracycline, as growth promoters can potentially accelerate the emergence of resistant bacterial isolates. Some authors suggest that the types and abundance of resistant genes in the human microbiome is more correlated to veterinary antibiotic use than the result of the selective process associated within clinical settings. Nevertheless, surveillance of resistant *Enterococcus* isolates requires attention and this should be undertaken by the relevant regulatory authority in China.

11.8 Lactic Acid Bacteria (LAB)

Consumers can be exposed to antimicrobial resistance-encoding genes carried not only by pathogenic bacteria, but equally well by probiotic microorganisms, such as lactic acid bacteria (LAB). These microorganisms are widely used in the food industry, as components in animal feed, and in the pharmaceutical industry. Generally, where resistance to antimicrobial compounds is expressed by LAB, it relates to the intrinsic nature of these microorganisms.

At present, disk diffusion, broth micro-dilution, agar dilution, and Etest can be used to test the susceptibility of LAB isolates. Despite the availability of these methods, a standardized or systematic procedure has yet to be developed for any of the members of this genus of bacteria. The latter protocols can be applied to LAB isolates, but results must be interpreted with caution.

Intrinsic resistance expressed by LAB is associated with genes that are chromosomally located and these are generally thought not to be mobilizable. In contrast, acquired resistance arises when antimicrobial resistance-encoding genes are located on mobile genetic elements, including conjugative plasmids. At present, several different antimicrobial compounds have been identified to which LAB isolates are naturally/intrinsically resistant and these include, aminoglycosides, β-lactams, cephalosporins, chloramphenicol, ciprofloxacin, colistin, clindamycin, erythromycin, fusidic acid, gentamicin, kanamycin, metronidazole, nalidixic acid, norfloxacin, nisin, penicillin G, polymyxin B, trimethoprim, streptomycin, sulfamethoxazole, and vancomycin. A viable option to respond to the intrinsic LAB resistance is to reinforce the LABs colonization ability in the intestine, thereby reducing the impact of an antimicrobial compound on the bacterium and making it possible for the normal bacterial flora to be maintained in the gastrointestinal tract to counter pathogen colonization. Qin Yuxuan *et al.* reported the erythromycin-resistant gene *ermB*, and the tetracycline-resistant genes *tet*(K), K, *tet*(L), and *tet*(M) in LAB strains [54]. The author also detected a streptomycin-resistance-encoding gene *ant6*, a gentamicin-resistant gene *aac (6')-aph (2")*, a tetracycline-resistant gene *tet*(M), and the sulfonamide-resistant genes *sulI* and *sulII* to be present in LAB isolates cultured form yogurt. In the study described by these authors, the *aph3*' gene was detected in 10 of 50 kanamycin-resistant LAB isolates; the *ECP* gene was identified in 4 of 41 LAB and *Streptococcus thermophiles* found to be resistant to cephalothin; and *tet*(M) was reported in 9 of 11 LAB isolates that were co-resistant to tetracycline. Han Junhua *et al.* detected the β-lactam-resistant gene *blr* in a single LAB isolate found to be resistant to cephalothin and confirmed through further experimentation that this gene was located on a plasmid [55]. Zhang Hongmei *et al.* reported that three LAB isolates could transfer ampicillin, streptomycin, and tetracycline-resistant plasmids to colibacillus recipient strains [56]. Further, Liu Chuanjie *et al.* confirmed that plasmids were detected from 81.2% of the yogurt LAB isolates and 18.8% of the resistant strains could transfer resistance *via* conjugation [57].

In China, findings from various studies indicate that all sectors of the food industry where LAB is used, including fermented food, animal feeds, and dietary supplements sectors, exhibit less than an ideal picture concerning resistant LAB isolates. Wang Mengjiao *et al.* recovered streptomycin-resistant strains from traditional Mongolian food [58]; Shi Lei *et al.* recovered 48 LAB isolates from yogurt in a Guangzhou market that were resistant to ciprofloxacin, gentamicin, kanamycin, streptomycin, and vancomycin, and 79.2% of these strains exhibited an MDR phenotype [59]. Zhou Meifang *et al.* recovered 16 LAB isolates from fermented milk products in Hangzhou, all exhibited multi-drug resistance [60]. In this collection, 10 LAB isolates were resistant to amikacin, six to cotrimoxazole, five to levofloxacin, five to ciprofloxacin, five to tobramycin, two to gentamicin, two to vancomycin, one to ceftazidime, one to cefepime, one to nitrofurantoin, and one to tetracycline. Among the probiotic isolates recovered from healthy human and dietary supplements by Zhang Lifang *et al.,* 15 *Lactococcus lactis* were resistant to sulfonamides and polymyxin B, 14 *Lactobacillus* species were resistant to sulfonamides, methoxy-pyrimidine, and polymyxin B, and five *Bifidobacterium* species were resistant to amikacin, bacitracin, ciprofloxacin, gentamicin, streptomycin, and sulfonamides [61]. In an on-going project conducted by these authors, designed to test the susceptibility of 120 LAB strains to a panel of 13 antimicrobial compounds, nine categories of resistance profile were identified, 82.2% of the *Lactobacillus* strains and 60% of *S. thermophiles* exhibited resistance, and 74.3% of *Lactobacillus* strains and 38.9% of *S. thermophiles* exhibited multi-drug resistance. In particular, 50% of the *Lactobacillus* species were resistant to cefotaxime, chloramphenicol, kanamycin, and vancomycin, and over 40% of *Streptococcus thermophiles* isolates were resistant to chloromycetin (data not yet published).

According to Guidelines for the Evaluation of Probiotics in Food by FAO/WHO, an antibiotics model should be established for the evaluation of probiotics. The multi-drug resistance detected in probiotics used by the food industry indicates that the government should make a greater effort to test the susceptibility of those probiotics that are used in food production, whilst reinforcing the monitoring of the species and determining bacterial counts for probiotic-containing products, so as to detect unsafe isolates and protect consumers' health in a timely manner.

11.9 Concluding Remarks and Future Direction in China

In summary, the problem of antimicrobial resistance is particularly pressing in China. The widespread use of antimicrobial agents in food animal production is associated with increasing resistance in food-borne pathogens, which subsequently may be transferred to humans, *via* the food chain. Therefore, there is an urgent need to conduct a systematic investigation of the occurrence of antimicrobial-resistant bacteria in animals, food, and in humans so as to investigate possible links and to identify any associated risk factors. Measures to limit the exposure of the microbiota generally to applied antimicrobials should be taken in order to preserve the efficacy of the current antimicrobial therapies used in China. Similarly, human behavior that gives rise to the extensive use of antimicrobial compounds must be also encouraged to change.

Currently, the general public in China believe that antimicrobial agents are universally efficacious and should therefore be applied in the first instance to virtually all ailments. People suffering from the common cold often take oral antibiotics, some even favor intramuscular or intravenous injection; both are practices that can no longer be supported. Apart from the recognized societal costs, this unchecked medical practice will continue to drive the emergence of resistant bacteria of importance to human, animal, and even environmental health. Therefore, a multi-stakeholder approach will be required to educate the corporate sectors in China, along with the general public in an effort to raise awareness and, importantly, seek to reduce the demand for these chemotherapeutic agents. In particular, it is also important to raise awareness of the threat of antimicrobial resistance among our healthcare professionals.

The Chinese government should also be encouraged to take the necessary measures that would seek to promote the use of as much of a compound as would be needed to effect a successful treatment in the least amount of time. A similar approach could also be adopted in parallel for food animal production. Moreover, the national regulator should seek the means to eliminate the use of chemotherapeutic agents of critical importance to human medicine from their use in animal production and implement banning from the food chain of any food that is found to be contaminated with bacteria resistant to antimicrobial agents.

These are challenging goals that will require the collaboration of relevant stakeholders, such as health professionals, the general public, agribusiness, pharmaceutical companies, media experts, and legislative bodies in order to restrict the use of antimicrobial compounds and to minimize or eliminate the misuse of these agents in food animals and humans. Efforts should be focused towards the improvement of management routines, regulatory control of the use of antimicrobial agents, implementation of prudent use guidelines, and, importantly, a joint monitoring approach to measure the use of antimicrobial agents and the emergence of bacterial antimicrobial resistance.

References

1 Rabatsky-Ehr T, Whichard J, Rossiter S, Holland B, Stamey K, Headrick ML, Barrett TJ, Angulo FJ, NARMS Working Group (2004) Multidrug-resistant strains of *Salmonella enterica* Typhimurium, United States, 1997–1998. *Emerg Infect Dis.* 10, 795–801.

2 Agunos A, Léger D, Avery BP, Parmley EJ, Deckert A, Carson CA, Dutil L (2013) Ciprofloxacin-resistant *Campylobacter* spp. in retail chicken, western Canada. *Emerg Infect Dis.* 19, 1121–1124.

3 Prats G, Mirelis B, Llovet T, Muñoz C, Miró E, Navarro F (2000) Antibiotic resistance trends in enteropathogenic bacteria isolated in 1985-1987 and 1995-1998 in Barcelona. *Antimicrob Agents Chemother.* 44, 1140–1145.

4 Crim SM, Iwamoto M, Huang JY *et al.* (2013) Incidence and trends of infection with pathogens transmitted commonly through food – Foodborne Diseases Active Surveillance Network, 10 U.S. Sites, 1996-2013. *MMWR.* 62, 283–287.

5 Woodford N, Tierno PM, Jr., Young K, Tysall L, Palepou M-FI, Ward E, Painter RE, Suber DF, Shungu D, Silver LL, Inglima K, Kornblum J, Livermor DM (2004) Outbreak of *Klebsiella pneumoniae* producing a new carbapenem hydrolyzing class a -lactamase, KPC-3, in a New York medical center. *Antimicrob Agents Chemother.* 48(12), 4793–4799.

6 Marchaim D, Navon-Venezia S, Schwaber M Carmeli Y (2008) Isolation of imipenem-resistant Enterobacter species: Emergence of KPC-2 carbapenemase, molecular characterization, epidemiology, and outcomes. *Antimicrob Agents Chemother.* 52(4):1413–1418.

7 Patel G, Huprikar S, Factor SH, Jenkins SG, Calfee DP (2008) Outcomes of carbapenem-resistant *Klebsiella pneumoniae* infection and the impact of antimicrobial and adjunctive therapies. *Infect Control Hosp Epidemiol.* 29(12), 1099–1106.

8 Rubin RJ, Harrington CA, Poon A, Dietrich K, Greene JA, Moiduddin A. (1999) The economic impact of *Staphylococcus aureus* infection in New York City hospitals. *Emerg Infect Dis.* 5, 9–17.

9 Phelps CE (1989) Bug/drug resistance. Sometimes less is more. *Med Care.* 27, 194–203.

10 Elaine S, Hoekstra RM, Angulo FJ, Tauxe RV, Marc-Alain W, Roy SL (2011) Foodborne illness acquired in the United States: Major pathogens. *Emerg Infect Dis.* 17, 7–15.

11 Han XF, Liu SL, Hou XG, Chen X, Peng Z, Zhu DM (2014) Characterization of antimicrobial resistances and molecular characteristics of *Salmonella* isolates from the pork production chain in Sichuan province, 2010–2011. *Chin J Epidemiol.* 5, 519–523 [in Chinese].

12 Wang J, Wang YD, Zheng ZR, Zhao SJ, Huang XM (2009) Study on susceptibility for avian *E.coli* and *Salmonella*. *Poult Sci.* 6, 8–10 [in Chinese].

13 Pang ZM, Jiao X, Liu WB, Gao S (2002) The surveillance for the antimicrobial resistance of *Salmonella Pullorum*. *Acta Veterin Zootech Sin.* 33, 377–383 [in Chinese].

14 Hu YJ, He YY, Wang YR, Cui SH, Chen QX, Liu GH, Chen Q, Zhou G, Yang BW, Huang JL, Yu HX, Li FQ (2015) Epidemic condition and molecular subtyping of ciprofloxacin and cefotaxime co-resistant *Salmonella Indiana* isolated from retail chicken carcasses in six provinces, *China. Chin J Prev Med.* 49, 716–721 (in Chinese).

15 Bai L, Lan RT, Zhang XL, Cui SH, Xu J, Guo YC, Li FQ, Zhang D (2015) Prevalence of *Salmonella* isolates from chicken and pig slaughterhouses and emergence of ciprofloxacin and cefotaxime co-resistant *S. enterica* Serovar Indiana in Henan, China. *PloS One.* 10, E0144532.

16 Bai L, Guo YC, Dong YP, Wang W, Du CM, Xu J, Li FQ (2014) Antimicrobial susceptibility analysis and molecular typing by pulsed-field gelelectrophoresis of *Escherichia coli* O157 isolated from food in China. *Chin J Food Hygiene.* 26, 422–428 [in Chinese].

17 Bai L, Guo YC, Lan RT, Dong YP, Wang W, Hu YJ, Gan X, Yan SF, Fu P, Pei XY, Jin Xu, Liu XM, Li FQ (2015) Genotypic characterization of Shiga toxin-producing *Escherichia coli* O157:H7 isolates in food products from china between 2005 and 2010. *Food Control.* 50, 209–214.

18 Liu YY, Wang Y, Walsh TR, Yi LX, Zhang R, Spencer J, Doi Y, Tian GB, Dong BL, Huang XH, Yu LF, Gu DX, Ren HW, Chen XJ, Lv LC, He DD, Zhou HW, Liang ZS, Liu JH, Shen JZ (2016) Emergence of plasmid-mediated colistin resistance mechanism MCR-1 in animals and human beings in China: A microbiological and molecular biological study. *Lancet Infect Dis.* 16,161–168.

19 Hasman H, Hammerum AM, Hansen F, Hendriksen RS, Olesen B, Agerso Y, Zankari E, Leekitcharoenphon P, Stegger M, Kaas RS (2015) Detection of mcr-1 encoding plasmid-mediated colistin-resistant *Escherichia coli* isolates from human bloodstream infection and imported chicken meat, Denmark 2015. *Euro Surveill.* 20, 30085.

20 Falgenhauer L, Waezsada SE, Yao Y, Imirzalioglu C, Kasbohrer A, Roesler U, Michael GB, Schwarz S, Werner G, Kreienbrock L (2016) Colistin resistance gene mcr-1 in extended-spectrum beta-lactamase-producing and carbapenemase-producing Gram-negative bacteria in Germany. *Lancet Infect Dis.* 16, 282–283.

21 Xian HX, Yang F, Yang H, Zhang HL, Wang B (2009) Study of antimicrobial resistance and inducible resistance of erythromycin and clindamycin in *Staphylococcus aureus* isolated from food samples. *Pract Prev Med.* 16, 1718–1720 [in Chinese].

22 Lv GP, Wang X, Wei XP, Li JS, Feng P (2013) Drug resistance and mecA gene analysis in foodborne *Staphylococcus aureus*. *J Environ Health.* 30, 1089–1091 [in Chinese].

23 Fan Q, Liu SL, Wu CM, Han XF, Zhou K, Liu DX, Hou XG (2015) Drug resistance changes and analysis of beta-lactam drug resistance genes in *Staphylococcus aureus* from fresh milk. *Food Sci.* 36, 147–151 [in Chinese].

24 Zhao XL, Liu HQ (2015) Antimicrobial resistance of *Staphylococcus aureus* isolated from milk. *Animal Husb Vet Med.* 47, 112–113 [in Chinese].

25 Zhuge SY, Guo SH, Su AR, Li XG (2013) Isolation, identification and drug resistance of foodborne and pathogenic *Staphylococcus aureus*. *Pract Prev Med.* 20, 1395–1397 [in Chinese].

26 Wang W, Guo YC, Pei XY, Hu YJ, Bai L, Sun AP, Liu JK, Fu P, Li FQ (2013) Genetic characterization and antimicrobial susceptibility analysis of methicillin-resistant *Staphylococcus aureus* isolated from ready-to-eat food and pig-related sources in China. *J Hygiene Res.* 42, 925–931 [in Chinese].

27 Ruizpalacios GM (2007) The health burden of *Campylobacter* infection and the impact of antimicrobial resistance: playing chicken. *Clin Infect Dis.* 44, 701–703.

28 Jorgensen F, Ellis-Iversen J, Rushton S, Bull SA, Harris SA, Bryan SJ, Gonzalez A, Humphrey TJ (2011) Influence of season and geography on *Campylobacter jejuni* and *C. coli* subtypes in housed broiler flocks reared in Great Britain. *Appl Environ Microbiol.* 77, 3741–3748.

29 EFSA, ECDC (2013) Rise in human infections from *Campylobacter* and *E. coli*, whilst Salmonella cases continue to fall. EFSA and ECDC 2011 Zoonoses Report.

30 Crim SM, Iwamoto M, Huang JY *et al.* (2013) Incidence and trends of infection with pathogens transmitted commonly through food – Foodborne Diseases Active Surveillance Network, 10 U.S. Sites, 1996–2013. *MMWR.* 62, 283–287.

31 Garin B, Gouali M, Wouafo M, Perchec AM, Pham MT, Ravaonindrina N, Urbès F, Gay M, Diawara A, Leclercq A, Rocourt J, Pouillot R (2012) Prevalence, quantification and antimicrobial resistance of *Campylobacter* spp. on chicken neck-skins at points of slaughter in 5 major cities located on 4 continents. *Int J Food Microbiol.* 157, 102–107.

32 Gong ZH, Zhang K, Wang LP, Wang J, Sui ZF, Wang HW, Luo QP, Wang JL, Xu JY (2014) Surveillance and analysis of *Campylobacter* in chicken. *Chin Poult.* 36, 59–62 [in Chinese].

33 Li CC, Chiu CH, Wu JL, Huang YC, Lin TY (1998) Antimicrobial susceptibilities of *Campylobacter jejuni* and *C.coli* by using E-test in Taiwan. *Scan J Infect Dis.* 30, 39–42.

34 Wang Y, Dong Y, Deng F, Liu D, Yao H, Zhang Q (2015) Species shift and multidrug resistance of *Campylobacter* from chicken and swine, China, 2008-14. *J Antimicrob Chemother.* 71, 666–669.

35 Xia C, Naren GW, Wu CM, Yang W, Lei D, Xia LN (2010) Prevalence and antimicrobial resistance of *Campylobacter* isolates in broilers from China. *Vet Microbiol.* 144, 133–139.

36 Chen X, Liu SL, Wu CM, Han XF, Chen LN, Lu SQ (2013) Contamination analysis and PFGE typing of *Campylobacter jejuni* isolated from chicken production chain. *Chin J Zoonoses.* 29, 199–205 [in Chinese].

37 Li YL, Li BB, Zhao QH, Shi ZX, Wei JC, Shao DH, Ma ZY(2014) Macrolide resistance mechanism in *Campylobacter* isolates of poultry origin in Shanghai area. *Chin J Prev Vet Med.* 36, 327–330 [in Chinese].

38 Zhang M, Li Q, He L, Meng F, Gu Y, Zheng M (2010) Association study between an outbreak of Guillain-Barre syndrome in Jilin, China, and preceding *Campylobacter jejuni* infection. *Foodborne Pathog Dis.* 7, 913.

39 Xue F, Luan J, Zhang XR, Zhu CQ, Xu F, Chen GJ, Zhang CY, Xu BX, Jiang Y, Lu C (2009) Susceptibility of different species of animal hosts to *Campyelobacter jejuni* infection and its drug-resistance. *Chin J Zoonoses.* 25, 1206–1209 [in Chinese].

40 Bai Y, Cui SH, Xu X, Li FQ (2014) Enumeration and characterization of *Campylobacter* species from retail chicken carcasses in Beijing, China. *Foodborne Pathog Dis.* 11, 861–867.

41 Chao GX, Jiao XN, Qian XQ, Xu Q, He R, Zhou LP (2006) Contamination status and drug resistacne of foodborne pathogens in Yangzhou. *Chin J Food Hygiene.* 18, 23–25 [in Chinese].

42 Yan H, Wang B, Shi BZ, Meng HC, Shi L (2010) Study on serotype and antibiotic resistance in *Listeria monocytogenes*. *J Chinese Antibiot.* 35, 774–777 [in Chinese].

43 Jia J, Bi ZW, Chen YZ, Hou PB, Zhang M, Shao K, Bi ZQ (2011) Antibiotic resistance and molecular typing of *Listeria monocytogenes* from foods in Shandong province from 2009 to 2010. *Chin J Prev Med.* 45, 1065–1067 [in Chinese].

44 Eunhye B, Dokyung L, Seok J, Hyangmi A, Mijin K, Kyungjae K, Kangoh L (2014) Namjoo HaAntibiotic resistance and MLST analysis of foodborne pathogenic *Listeria Monocytogenes* in China in 2012. *Chin J Food Hygiene.* 26, 537–542.

45 Khan S, Sung K, Marasa B, Min S, Kweon O, Nawaz M, Cerniglia C(2015) Draft genome sequence of multidrug-resistant *Enterococcus* faecium clinical isolate VRE3, with a sequence type 16 pattern and novel structural arrangement of Tn1546. *Genome A.* 3, e00871–15.

46 Diaz L, Tran TT, Munita JM, Miller WR, Rincon S, Carvajal LP, Wollam A, Reyes J, Panesso D, Rojas NL, Shamoo Y, Murray BE, Weinstock GM, Arias CA (2014) Whole-genome analyses of *Enterococcus* faecium isolates with diverse daptomycin MICs. *Antimicrob Agents Ch.* 58, 4527–4534.

47 Pesavento G, Calonico C, Ducci B, Maqnanini A, Lo Nostro A (2014) Prevalence and antibiotic resistance of *Enterococcus* spp. spp. isolated from retail cheese, ready-to-eat salads, ham, and raw meat. *Food Microbiol.* 41, 1–7.

48 Li XN, Li HM, Li B, Gong XJ (2016) Food poisoning caused by *Enterococcus*. *Prev Med Tribune.* 12, 498 [in Chinese].

49 Wu CL, Shi CL, Zhou M, Yang JL, Shi XM (2011) Development and evaluation of a real-time PCR system for *Enterococcus* spp. detection in food samples. *J Food Sci Biotech.* 30, 779–787 [in Chinese].

50 Jiang K, Zhang DL, Jin YF, Chen XZ (2011) Establishment of LAMP rapid detection method for *Enterococcus* in dairy products. *Chin Dairy Ind.* 39, 51–53 [in Chinese].

51 Duan ZG, Wang YB, Hu H, Jin Y, Cui BA (2009) Identification of *Enterococcus* from retail pork and detection of virulence factor gene. *Chin Agri Sci Bull.* 25, 20–23 [in Chinese].

52 Li B (2001) Study of the main spoilage microorganisms in Tofu and establishment of HACCP. Doctoral thesis. China Agricultural University [in Chinese].

53 Abriouel, H. (2007) Comparative analysis of genetic diversity and incidence of virulence factors and antibiotic resistance among enterococcal populations from raw fruit and vegetable foods, water and soil, and clinical samples. *Int J Food Microbiol.* 123, 38–49.

54 Qin YX, Li J, Wang QY, Gao KX, Zhu BL, Lv N (2013) Identification of lactic acid bacteria in commercial yogurt and their antibiotic resistance. *Acta Microbiol Sin.* 53, 889-897 (in Chinese).

55 Han JH. Li SS, Pei JW, Chen DH, Zhang BL (2013) Possible connections between the antibiotic-related plasmids of potentially probiotic *Lactobacillus* strains and the antibiotic resistance. *Sci Tech Food Ind.* 34,181–191 [in Chinese].

56 Zhang HM, Li FJ, Liu XL. (2010) Analysis of resistanc lactc acid bacteria isolated from some pickled food. *Food Ferment Ind.* (Editorial) 36(4):25–27 [in Chinese].

57 Liu CJ, Tan QQ, Zhu KN, Chen XX, Cheng DQ (2014) Assessment on the potential biosafety threat of lactic acid bacteria isolated from fermented dairy products in Hangzhou. *Chin J Microecol.* 26, 526–533 [in Chinese].

58 Wang MJ, Li SY, Wei W, He WY, Li SF (2013) Antimicrobial susceptibility test of lactic acid bacteria isolated from horse milk. *Food Sci Tech.* 38, 7–11 [in Chinese].

59 Shi L, Li YL, Liang NY, Dong CY, Meng HC, Yan H (2014) Antibiotic resistance of lactic acid bacteria in yogurt from Guangzhou. *Mod Food Sci Tech.* 30, 245–250 [in Chinese].

60 Zhou MF, Liu CJ, Tan QQ, Zhu KN, Cheng DQ (2014) Isolation and identification of *Lactobacillus* from fermented dairy products in Hangzhou. *Chin J Microecol.* 26, 526–533 [in Chinese].

61 Zhang LF,Tian HT, Zhang YL, Guo XH, Luo YB (2009) Antibiotic susceptibility analysis of lactic acid bacteria and *Bifidobacteria* from healthy human and health products. *J Chin Inst Food Sci Tech.* 9, 144–151 [in Chinese].

Part 3

Food Chemistry

12

Food Additives

Baoguo Sun and Jing Wang

Beijing Technology and Business University, China

12.1 Introduction

12.1.1 The Concept of Food Additives

The "Food Safety Law" defines food additives as "any synthetic compound or natural substance added to a food to improve its quality, color, fragrance and flavor, or meet the needs of preservation, freshness, and processing."

The *Codex Alimentarius* defines food additives as "any non-nutritional substance not normally consumed as food itself and not normally used as a typical ingredient of food, the intentional addition of which to food for a technological purpose in the manufacture, processing, preparation, treatment, packaging, transport or storage of such food results in its or its by-products becoming a component of or otherwise affecting the characteristics of such foods."

The European Union definition for food additives is "any substance intentionally added to a food during the process of manufacture, processing, preparation, treatment, packaging, transport or storage for a technological purpose." In the United States, food additives are defined as "any substance or a mixture of substances not normally used as a basic ingredient of food exists during the process of production, processing, storage and packaging." The definition of food additives in Japan is "any substance added to a food to mix, infiltrate or for other purposes during the process of production, namely food processing, for a preservative purpose."

Food additives generally have the following three characteristics: (a) they are the substances added to food and cannot be consumed alone as food themselves, (b) they include synthetic substances as well as natural substances and (c) the purpose of addition is to improve the quality, color, fragrance, flavor of food, and to meet the demands of preservation, freshness and processing.

12.1.2 The Functional Classification and Effects of Food Additives

12.1.2.1 The Functional Classification of Food Additives

China's "Hygienic Standards for the Use of Food Additives" divides additives into 23 types, according to their various functions: acidity regulators, anti-caking agents,

Food Safety in China: Science, Technology, Management and Regulation, First Edition.
Edited by Joseph J. Jen and Junshi Chen.

defoaming agents, antioxidants, bleach, leavening agents, chewing gum base, colorants, color fixatives, emulsifiers, enzyme preparation, flavor enhancers, flour treatment agents, coating agents, humectants, nutrient supplements, preservatives, stabilizing agents, coagulants, sweetening agents, thickening agents, food spices and food industry processing aids.

12.1.2.2 The Effects of Food Additives

In order to ensure the quality of the product during processing, all foods must contain suitable additives based on the product features [1]. Food additives play an important role in the following aspects employed in the food industries:

1) *Improve and enhance the quality and sensory properties of food.* Food color, fragrance, flavor, shape and texture are important indicators for quality. Some unit operations during food processing can easily cause the declination of food sensory quality. According to the "Standards for the Use of Food Additives," adding appropriate colorants, color fixatives, edible flavors, thickening agents, emulsifiers, quality improvers and such can obviously improve the sensory quality of food and meet the requirements of customers for food flavor and taste.
2) *Maintain and improve the nutritional value of food.* Some nutrients in food can be easily changed during processing and storage by adding food preservatives or antioxidant preservatives during the process of food production in accordance with the relevant provisions. In addition, they can prevent oxidation and deterioration, avoid nutrient loss and play an important role in maintaining food nutrition. Adding nutrient enhancers to the food can improve the nutritional value of food itself, prevent malnutrition and promote nutritional balance to improve the level of people's health.
3) *Maintain food safety and prolong the shelf life of food.* Food additives play a significant role in maintaining food safety and prolonging the food's shelf life. Within the scope of the world today, the top food safety problem is disease caused by pathogenic microbial contamination of food. Many foods without preservative measures decay soon after leaving the factory, causing serious harm after consumption. The usage of preservatives, antioxidants and anti-staling agents can prolong the food shelf life and guarantee inherent quality during the warranty period.
4) *Facilitate food processing, storage and transportation*. Food additives can satisfy the needs of lubrication, defoaming, leaching and stability, as well as solidification in the process of food production.
5) *Meet the needs of different people.* All kinds of sweetening agents are born of necessity to meet the demands of diabetics who cannot eat sucrose. In infant growth and development, a variety of nutrients are needed. Therefore, formulas with minerals and vitamins have been developed.

12.1.3 Principles for the Use of Food Additives

12.1.3.1 Technological Necessity in Food Processing

The "Food Safety Law" and its implementing regulations, relevant law, and standards in China make a clear and specific provision for the censor of technological necessity in food additives. The law requires that food additives are technologically necessary, safe and reliable after a risk assessment and before being included in a permitted scope. The law also requires that the use of food additives should not hide food deterioration or cover up the quality defects of the food itself or during the process of food production. It shouldn't aim at doping, adulterating, faking or reducing the nutritional value of food itself.

12.1.3.2 Safety and Reliability Without any Health Hazards to Humans

Food additives must undergo a rigorous risk assessment to ensure their safety on the basis of the established standard for usage scope and amount. At present, the scope and amount specified in the "Hygienic Standards for the Use of Food Additives" is based on a scientific assessment that can effectively guarantee that it will not bring any health hazards to consumers.

12.1.3.3 The Use of Food Additives Approved by the Chinese Government

China carries out a registration system for food additives where a directory lists three items: (a) the substance that can be used as a food additive, (b) the specific usage scope and amount and (c) in which foods the substance is permitted to be used.

12.1.4 The Effects of Food Additives in the Modern Food Industry

Humans have a long history in the employment of food additives. The application of food additives has helped food processing get rid of the original small cottage industry and gradually form the modern food industry. Thus, food additives are called, metaphorically, the soul of the modern food industry.

Food additives are an integral part of the industry, as well as an important driving force and source of food industry innovation and development. Food additives are closely related to either the improvement of food processing and the use of new equipment, or the research of new products and the improvement of product quality. They are necessary for food manufacturing and modern food industries. The constant emergence of new food additives ensures that the food industry can provide food for consumers with all kinds of demands, and they play a significant role in the national economy and people's livelihood.

12.2 The Development History of Food Additives

12.2.1 The Application History of Food Additives

The employment of food additives has a long history within the world. The earliest records of adding pigments to food can be traced back to ancient Egypt, around 1500 BC, where local candy makers employed natural extracts to improve the color and luster of their candies. Around 300–400 BC, people began to artificially dye their wine. By the middle of the nineteenth century, people added a spice called saffron to certain foods for decorative purposes.

The history of the earliest employment of food additives in China can be traced back to the Dawenkou culture period 6000 years ago when the brewing method was generally known. Around 2700 years ago, the invertase in *Saccharomyces cerevisiae* was used as a kind of food additive for brewing purposes [2, 3]. The employment of natural pigments in food also appears in earlier records in such ancient books as *Shen Nong's Herbal* and *Bencao Tujing*, which recorded the use of gardenia dyeing. Red kojic rice was used in wine brewing during the Han Dynasty. The history books said that "the south people made wine with unique color and taste." The *Qi Min Yao Shu*, written by Jia Sixie, an agricultural scientist of the Northern Wei Dynasty (sixth century AD), recorded the method of extracting natural pigments from plants. The employment of cinnamon to enhance aroma began in the Zhou Dynasty. The traditional Chinese tofu solidifier – bittern was applied around the time of the Eastern Han Dynasty. The *Food Sutra* and *Qi Min Yao Shu* of the Northern Wei period exactly recorded the solidification of soyabean milk using bittern and gypsum.

The *Food Sutra* recorded that people employed fermentation technology for the first time in steamed bread-making in the Wei Jin period. At the same time, sodium carbonate was added to dough in order to promote dough fermentation. Since the Southern Song Dynasty, twisted dough-strips have been considered attractive and affordable food on the breakfast table. A formula of "one alum, two alkali, three salt" was recorded, in which "one alum" means alum, chemically called aluminum potassium sulfate, while "two alkalis" refers to trona and sour dough, chemically called sodium carbonate and sodium bicarbonate, respectively.

The volume of science and technology in the *Song Dynasty History* recorded that nitrite, as an antiseptic and for color development of meat products, was used in the production of bacon during the Southern Song Dynasty and was introduced to Europe in the thirteenth century. The Sui Wendi era (AD 541–604) saw the invention of waxed yellow orange preservation technology. Kimchi, with a history spanning thousands of years, employed food additives during its manufacturing process.

In contemporary society, many places still retain the production of red yeast rice wine and spiced pork inherited from ancient traditions, which embodies the wide application of food additives in ancient China. The earliest food additives were mostly derived from natural substances.

The earliest chemical synthesis of food additives happened in 1856 when W. H. Perkins, a British chemist, obtained aniline purple dye (mauveine) from coal tar, which replaced the former use of natural pigments in a very short period of time. By the end of the nineteenth century, the rapid development of the chemical industry truly contributed to the modern food additives industry. For instance, the Monsanto company invented saccharin in 1901 and Japanese chemists successfully extracted sodium glutamate, namely aginomoto from seaweed in 1908.

12.2.2 The Regulatory Process of Food Additives

After the Industrial Revolution, the food industry developed rapidly. In the late nineteenth and early twentieth centuries, color additives were widely used without examination or approval in various kinds of popular food in the European and American markets, such as ketchup, mustard, jelly and wine. More than 80 kinds of synthetic pigments appeared on the market, some of which were used in the textile industry rather than the food industry. Many food pigments never went through a determination of toxicology and other negative effects.

In order to standardize the use of food additives, the Joint Expert Committee on Food Additives (JECFA) and the Codex Committee on Food Additives (CCFA) (the name was changed to the Codex Committee on Food Additives and Contaminants (CCFAC)in 1988) were established internationally in 1955 and 1962, respectively. The purpose of these committees was to focus on the safety of food additives, establish relevant standards and detection methods, evaluate the safety of food additives and put forward recommendations to the relevant countries and organizations so that food additives could gradually step onto the road of healthy development.

Though China's comprehensive and systematic research and management on food additives started late, it developed faster [4–6]. Shortly after the founding of the People's Republic of China, some regulations were issued in order to oppose the use of certain additives in food production. The Ministry of Health issued "Regulations on the Usage Amount of Saccharin in Food" in 1954, which explicitly limited the usage amount of the saccharin in cool and refreshing drinks, bread, cake and cookies supplied to children. In 1960, the "Interim Measures for Administration of Synthetic Food Dyes" was put forward, which proposed that a diet should involve no dyes as far as possible and should employ non-toxic natural edible pigments first if they must be included. The interim measures also explicitly listed eight classes of food that could not generally use synthetic dyes.

The Scientific Research Cooperation Group of National Food Additives Hygiene Standards was established in 1973 and began a comprehensive study of food additives, and carried out the formulation work of standardized scientific research on food additives. The "Hygienic Standards for the Use of Food Additives" (GBn50-1977) and the "Measures for the Hygienic Administration of Food Additives" were formulated in 1973 and internally implemented. The State Council promulgated the "Regulations on the Administration of Food Hygiene of the People's Republic of China" in 1979, which stipulated that "the use of needed food additives during the process of food production and processing must strictly observe the regulations on the use of variety, dosage and usage scope and misuse is forbidden."

The National Technical Committee of Food Additives Standards was founded in 1980. Its obligation was to draft and examine the hygienic standards for the use of food additives and quality standards and provide reasonable suggestions to government departments on some management problems of food additives. The mandatory national standard "Hygienic Standards for the Use of Food Additives" (GB2760-1981) was formally published in 1981, based on GBn50-1977, which was originally and internally implemented and included measures for administration. The standard included the type, name, usage scope and maximum usage amount of food additives. It also listed 213 kinds of food additives, 207 kinds of flavoring agents permitted and temporarily permitted, which included 73 kinds of natural edible spices and 110 kinds of synthetic edible spices, as well as 24 kinds of spices temporarily permitted. The "Interim Measures for Management of Production of Chemical Products Used for Food" and the "Trial Measures for Management of National Spice Products Used for Food" were issued in the early 1980s and contained a system of license management regarding chemical synthetic additives and spice production enterprises. The standard was revised for the first time in 1986 and included 23 classes and 833 kinds of food additive, among which were 693 kinds of spice.

The "Food Additives Classification and Code" (GB12493-1990) was formulated in 1990 with reference to the Food and Agriculture Organization of the United Nations and the World Health Organization (FAO/WHO) and the Codex Alimentarius Commission CAC/Vol IV (1983) X files, which classified and encoded food additives. The "Chinese Institute of Food Science and Technology" and the "Chinese Food

Additive Production Application Industry Association" were established in succession in 1993. The "Classification and Code of Food Flavorings" (GB/T14156-1993) was formulated in 1993.

The "Hygienic Standards for the Use of Nutritional Fortifiers in Foods" was formulated in 1994 (GB14880-1994), and listed the variety, usage scope and maximum usage amount of nutritional fortifiers permitted in China. The "Hygienic Standards for the Use of Food Additives" (GB2760-1996) went through a second revision in 1996 and adopted the classification, code and encoding of GB12493-1990 and GB/T14156-1993, which increased the FEMA number and divided food additives into 22 classes according to their function. A third revision of the standard was carried out in 2007, namely GB2760-2007, which specified all permitted food additives. In GB2760-2007, 396 types were directly used, while 1528 were spices and 104 were processing aids for food. A fourth revision came in 2011, namely GB2760-2011, which specified 2310 types of permitted food additives, including 59 processing aids, 1826 flavoring agents, 35 chewing gum bases, 51 enzyme preparations and 229 other categories of food additive. The "Standards for the Use of Nutritional Fortifiers in Foods" went through an amendment (GB14880-2012) in 2012. The "Standards for the Use of Food Additives" was revised for the fifth time in 2014, becoming the "National Food Safety Standards – Standards for the Use of Food Additives" (GB2760-2014) and implemented on May 24, 2015.

12.3 The Status Quo for Food Additives

12.3.1 The Development Status of the Food Additives Industry

As shown in Figure 12.1, due to the rapid development of the food industry, food additives businesses developed fast in China from 2001–2013, with a gradual increase in total production and output value year on year [7]. The statistical total output of the food additives industry was 8.85 million tons in 2013 with a year-on-year growth of 7% and sales of about 87 billion yuan with a year-on-year growth of 5%.

At present, the varieties of food additives used worldwide are up to more than 25 000 different kinds (80% were flavoring agents). Of those, 3000–4000 were directly used, including 600–1000 food additives that were frequently used. The United States permits more than 5000 varieties of food additive, while China permits more than 2500. The global food additives industry has grow rapidly at the rate of 4%–6% each year. Since the 1980s, the consumption of food additives in the US has grown at a rate of 4% annually, on average, while the consumption of food additives in China, Japan and western European countries has increased yearly. The size of the domestic food additives market increased to nearly 150 billion yuan. At present, China's total output value for food additives accounts for about 15% of the total amount of international trade, which provides a broad space and prospects for the development of food additives in China.

According to incomplete statistics, there are about 1500 food additive production enterprises in China at present, with 500 such enterprises above the designated size [8]. The commonly used varieties of food additives, include flavoring essences, sweeteners, preservatives, anti-staling agents, thickening agents, emulsifiers, quality improvers, acidulants and nutritional enhancers. All are produced internally and the output is ranked among the highest in the world. Besides meeting the demands of the domestic

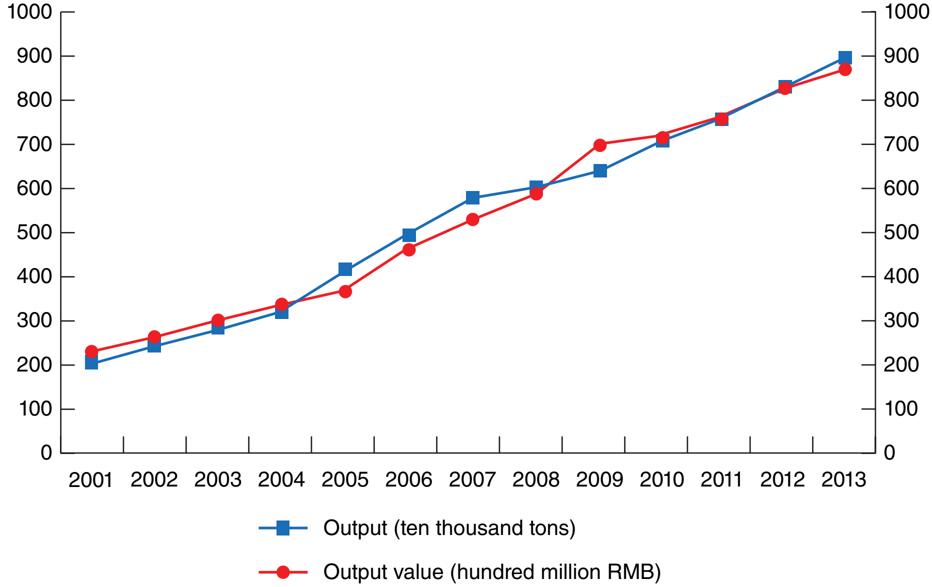


Figure 12.1 The output of main varieties of food additives in 2001–2013. *Source:* Data from China food industry yearbook (2001–2013.)

market, exporting many of the products is also common. Some of the products are dominant in the overseas market. Overall, food additives share about 2% of the food industry in China.

12.3.2 The Standards and Management of Food Additives

The three main standards for food additives in China are the usage standard, the product standard and the detection method.

The “Standards for the Use of Food Additives” (GB2760) and the “Standards for the Use of Nutritional Fortifiers in Foods” (GB14880) are the two primary standards that must be complied with during the employment of food additives. GB2760 specifies the definition, category, variety, usage scope, usage amount and usage principles of permitted food additives and requires that the employment of food additives should not try to obscure the quality defects of food itself in the course of processing or mixing, by adulterating or faking. GB14880 stipulates the definition, usage scope and usage amount of nutritional fortifiers. At present, there are about 200 kinds of nutritional fortifiers permitted.

The product standards for food additives consist of technical indicators and corresponding identification and detection methods, which include varietal characteristics, specifications, technical indicators, test methods, inspection rules, marks, labels, packaging, storage and transportation. There were 485 items in the product standards on food additives in China before the clean up and integration of the standards in 2013. A total of 601 items are planned to be formed through integration, transformation and revision after clean up.

According to the provisions of the "Measures for the Hygienic Administration of Food Additives," any new varieties of food additives aren't listed in the "Standards for the Use of Food Additives" or in announcements by the Ministry of Health. Any food additives which have been listed in the "Standards for the Use of Food Additives" or Ministry of Health announcements for which the usage scope and the usage amount need to be expanded require the approval of the Ministry of Health before production, sale and use. The production, operation and use of food additives needs to be approved and must provide the name and source of raw materials, the chemical structure, the physical and chemical properties, and the toxicological evaluation report at provincial level presented by an inspection agency. The health administrative departments must confirm hygienic inspection reports from three consecutive batches of products, usage scope and usage amount, a report on the effect of experimental use, detection methods of the given kind of food additive in food, the quality standards or specifications of products, product samples, labels (including introductions) and other relevant materials according to the provisions of the administrative measures. The supervisors of the local provinces, municipalities and autonomous regions and the Department of Health must put forward the preliminary examination opinions regarding these materials. Then the National Cooperation Group for Hygienic Standards of Food Additives prequalifies these materials, which will then be submitted to the National Technical Committee for Standardization of Food Additives for review. The varieties that pass the review will be authorized to issue after being reported and audited by the Ministry of Health and the State Bureau of Technical Supervision [9].

12.3.3 Problems During the Use of Food Additives

Although the safety standards and regulatory system of food additives are developing continuously in China, standards and supervision mechanisms of food additives remain to be completed, owing to the rapid development of the food additives industry. Security problems surrounding food additives happen occasionally due to some enterprises' blind pursuit of profit and other factors. It is a phenomenon within food processing plants that different levels of illegal use, usage beyond scope and excessive use exist during the employment of food additives.

12.3.3.1 Use of Illegal Additives

It is known that the melamine "poisonous milk powder" incident is a typical case in which people used illegal additives in food. It is a phenomenon that people use illegal additives in foods, such as Sudan red in chili sauce and its products, Kentucky Fried Chicken and red yolk duck eggs. Food additives must be of food grade, but some food production enterprises employ additives of industrial grade to reduce costs, such as industrial grade ammonium bicarbonate which is used as a leavening agent. Another activity is the obscuring of food quality problems by employing food additives, such as adding preservatives in stale pot-stewed food or adding spices and pigments to rotten meat.

12.3.3.2 The Use of Food Additives Beyond Scope

In April 2011, CCTV exposed that several supermarkets in Shanghai sold steamed corn bread without any corn flour, but dyed it using citric yellow from the wheat flower.

Citric yellow is a kind of food additives permitted in puffed foods, ice cream and juice drinks, but not in steamed buns. This is a typical illegal use of food additives beyond scope.

12.3.3.3 Excessive Use of Food Additives

It is a major problem that people add food additives optionally that are not in accordance with state-specified standards at present. Examples are excessive use of the colorant nitrite to process meat, excessive use of the preservative benzoic acid, sweeteners saccharin sodium, cyclamate and artificial synthetic pigment in milk beverages, fruit juice drinks and candied fruits to prolong the storage life and reduce cost, excessive use of colorants and preservatives in fruit jelly and protein jelly, and excessive use of colorants, preservatives and sweeteners in pickles.

12.3.3.4 Label does not Conform with the Provisions

Some enterprises ignore the requirements of the “Food Safety Law,” the “General Principles of Prepackaged Food Labels,” and other laws and regulations during the process of actual production and management of food and food additives. They identify food additives incorrectly or untruthfully and mislead consumers through “No Added” labels, which seriously violates the consumers’ right to know. These problems not only make food additives fodder for media criticism, as well as the focus of attention, but also deepen consumers’ confusion about food additives.

Due to the above-mentioned problems regarding the use of food additives, as well as false reports from some media, most consumers turn pale at the mere mention of food additives, which causes serious misunderstanding of the food additive concept.

12.3.4 The Reasons Why Food Additives are Demonized in China

The position of food additives being demonized has not occurred in developed countries and other developing countries in the world. In China, there is an intensified trend [10]. In fact, none of the food safety events so far in China that have caused harm to human health were induced by the legitimate use of food additives [11]. The main reasons why food additives are demonized in China are as follows.

12.3.4.1 Food Additives Take the Blame for Illegal Additives

From the exposure of major food safety incidents in recent years, such as “melamine milk”, “red yolk duck eggs” and “clenbuterol pork,” we can see that the well-known melamine, Sudan red and clenbuterol are not food additives, but illegal additives. In China, only the products listed in the “Standards for the Use of Food Additives” can be called food additives, while any others are deemed illegal. However, due to the lack of an accurate systematic and scientific knowledge of food additives, people get confused about the concept of both food additives and illegal additives. People tend to place blame on food additives and mistake them for the cause of food safety problems when some problems are really exposed because of the use of illegal additives. This is the main reason why the public misunderstands and resists food additives.

12.3.4.2 Individual Food Manufacturers Misuse Food Additives

Individual food production enterprises employ food additives to improve the quality of their products, yet discredit food additives on food labels at the same time. They use phrases such as “Excluding food additives” on food packaging or utilize other means such as advertising and the media to flaunt that their products do not contain any food additives. This misleads the public and deepens their misunderstanding of food additives. In fact, it’s hard to avoid using food additives in the process of food production. With the exception of fresh foods, the vast majority of products on the supermarket shelves employ food additives. The consumers’ three meals per day generally contain food additives. A label that says “Excluding food additives” on food packaging violates the identification rules for food additives and does not conform with the relevant national laws and standards for packaging labels. Such dishonest propaganda goes against the benign development of the food and food additive industries in China.

12.3.4.3 Inaccurate Reports from Individual Media Mislead the Public About Food Additives

The public’s misunderstanding of food additives derives from illegal additives rather than food additives. Due to individual media hype and inaccurate reports, relevant food safety events are exaggerated, misrepresented or even distorted in the process of propagation. For instance, much of the media said that the culprit in the Sanlu milk powder incident was a food additive. The Associated Press said that food additives caused the Sanlu infant milk powder scandal last year when talking about the problems of food additives in China in 2009 [12], a misleading example since it stated that melamine was a food additive when it wasn’t.

12.3.4.4 The Public Scientific Popularization of Food Additives and Food Safety in China is Still Weak

Various related departments, industry associations and experts have done a lot of work on scientific popularization of food additives and food safety in recent years, which has played a significant role in leading the public to correctly understand and think rationally about food additives; however, it is still weak at present. And the efforts to promote food safety are so small that the public cannot get the right information at the right time to get a scientific understanding of food additives and food safety. Thus, they still have fears and panics due to the lack of a scientific basis.

12.4 The Status and Development of Food Additives in Foreign Countries

12.4.1 The Regulation and Development of Food Additives in the US

The United States is the leading producer and user of food additives worldwide and the production values and variety of food additives rank first in the world [13]. In terms of the production, sales and employment within the food additive industry, the United States has a set of systematic and well-established management methods. In terms of risk assessment, standard setting and regulation of food additives, the United States also has strict rules [14]. The US Food and Drug Administration (FDA) is responsible for the management of food additives. The “Federal Food, Drug, and Cosmetic Act” (FD&C) of 1938 endows the FDA with the right to manage food as well as food ingredients. In the United States, the specifications of food additives must conform to the requirements of the Food Chemicals Codex (FCC). The code, to evaluate the quality of food additives for FDA, is an important basis of the standards and is quasi-legal in the United States. The United States issued the FCC (I) for the first time in 1966, and it has been supplemented and amended five times, with the latest version (V) being formally promulgated in 2004.

The FCC is the authoritative standard for the food additive industry and has been widely accepted internationally. Many food manufacturers regard the FCC standards as the basis for their production and processing. In terms of approval and supervision of food additives, the "Food and Drug Administration Law" stipulates that before the employment of additives, the user must put forward an application and can only use them after a complex, cumbersome approval process. This not only ensures the safe use of food additives, but also increases the cost of usage and prompts the food additive producers to observe the law [14].

Although America approves the widest variety of additives worldwide, it has strict rules over the dosage and purpose of food additives. Iron oxide can only be allowed to appear in cosmetics in the United States. In many other countries, it can be used as a food colorant. Fumaric acid calcium, which has its use limited in New Zealand, cannot be used in food flavorings in the US because its manufacturer failed to get effective approval [13]. Government regulation ensures that the producers strictly implement the national standards when carrying out the actual production so as to effectively guarantee food security for the people.

12.4.2 The Regulation and Development of Food Additives in the EU

The EU divides food additives into 26 classes and has specialized agencies, special laws and regulations to supervise food additives. The European Directorate General for Health and Consumer Protection (DG SANCO) is responsible for the application and approval of food additives. The European Scientific Committee for Food (SCF) is responsible for the safety assessment of food additives. The EU legislation adopts a "mixed system" on food additives, namely working out the laws and regulations on food additives by means of scientific evaluation and consultation that can be accepted by all members, and then publishing the list of service conditions and usage limits for food additives [14].

In addition, the EU requires that food manufacturers must list all food additives on food labels in order of descending weight and cannot mark the major categories generally. Food additives must appear in the most conspicuous place on the packaging and be indicated with bold-faced letters which cannot mislead consumers [13]. With the development of the food industry and investigation, the EU revises and modifies the management rules and standards on food additives constantly. A new list of food additives came into effect on June 1, 2013, which specified that only the food additives listed on the positive list could be put into use in certain conditions. The list played a significant role in strengthening consumer protection and providing food production enterprises with a clearer production standard [15]. The regulation 178/2002 of the European Parliament and Council was formally issued in 2002 and revised in 2003. This law is the most important food law in the EU, where food additives is a hot field [14]. The law provides the basis for ensuring the quality and usage safety of food additives.

12.4.3 The Regulation and Development of Food Additives in the UK

The Food Standards Agency regulates and manages the usage standards for food additives and establishes a information disclosure system, which stipulates that when the employment of certain food additives is controversial, the Food Standards Agency will reveal the different views from various institutions and establish a list showing the companies who voluntarily ban such food additives. When the authority releases the information, consumers can choose whether to buy the food or not autonomously. Therefore, the health hazards brought by such additives can be effectively circumvented [13]. The British Government stresses that the public has a right to know the employment of additives in the food they select and specifies that food additives must be listed on food labels and potential allergens also need to be indicated on the outer packages. Such supervision patterns greatly reduce the public's fear of food additives [13].

At present, all the countries are working to develop new food additives, especially functional food additives. To meet the different needs of customers, a variety of new products have appeared and the food additive industry is full of prosperity and vitality. Britain, for example, developed polyphosphate, which can be used as a buffering or chelating agent in food and acts as an antioxidant in fruit juice, as well as other carbonated drinks because it can effectively control the pH of the finished products. A food company in the United States extracted beet fiber from beet pulp, which was employed in baked food and bread because it has low calories, a light color and flavor, and will not affect the taste or color of the finished products or their shelf life. The Frito-Lay company in the US exploited α-hydroxy acid glycol ester in a recipe that can endow more crunch on potato and corn chips, as well as other recreational foods [16].

12.5 The Development Trend of Food Additives in the Future

12.5.1 Natural Green Food Additives Have Become the Main Development Direction for the Future

Domestic natural antioxidants such as tea polyphenols, natural sweeteners, licorice extract, natural antibacterial allicin, functional natural pigments and natural spices are favored by the international market at present as returning to nature has become an irresistible trend. Some chemical synthetic food additives are banned from use, such as the synthetic pigment cream yellow. The sales of natural edible pigments account for about 90% of the market in Japan and about 80% in the United States. China, with its vast territory and abundant resources, has a tradition of dietic medicine over thousands of years. It has a unique advantage for developing natural additives compared with Europe and Americ, and therein lies a huge potential for the development of natural green food additives in China.

12.5.2 The Exploitation and Application of Functional Food Additives Has Become an Important Research Direction

With the unceasing improvement in people's material living standard, physiological dysfunction caused by obesity is becoming more common. The application of sweeteners with high sweetness, low calorie foods and fat substitutes will become more and more extensive. Typical functional food additives are as follows: oligosaccharides such as oligofructose, galacto-oligosaccharides, xylo-oligosaccharide, sorbose, soybean oligosaccharides; soybean lecithin; vitamins such as vitamin E, vitamin C and beta-carotene; and other substances, polyphenols and flavonoids, etc [17].

Japan was one of the first countries worldwide to develop and promote the use of functional food ingredients whose main roles are as follows: improve intestinal function, control weight, regulate blood sugar, prevent dental caries, keep bone health, adjust blood pressure, regulate cholesterol, and so on. The various kinds of end products include drinks, lactic acid bacteria beverages, leisure food, cereals and protein foods.

China has a certain foundation and history of research and development in functional food additives, such as red yeast rice (which has the function of reducing blood fat), liquorice sweets (protects the liver), xylitol (suitable for diabetics), bamboo leaf antioxidants, curcumin and lycopene (various physiological functions), among others. All have been widely used in all kinds of food.

12.5.3 Biotechnology Promotes the Development of the Food Additive Industry in China

Because of the world energy crisis and the requirements needed for sustainable development, biotechnology has been widely used in the production of fuel, drugs and fine chemicals due to its low energy consumption and low pollution of the environment. The extraordinary popularity of its application in food additive production is not only attributed to the advantage of sustainable development, but more to its natural characteristics.

Many food additives employ biotechnology at present. For instance, xylitol, mannose alcohol and sweet peptide can be produced by fermentation, seasonings are being produced by enzyme technology and the Maillard reaction has been applied industrially. Moreover, the natural preservative poly-lysine with good anti-corrosion performance has been produced industrially through fermentation in Japan [18].

The development of genetic engineering, cell engineering, membrane separation technology, nanotechnology and other relevant fields will play a positive role in promoting the application of biotechnology in the preparation of natural food additives [19].

12.5.4 A Singular Food Additive Develops in the Direction of Compound Food Additives

Compound food additive products are composed of two or more of different kinds of food additives and ingredients. They are combined through physical methods in specific proportions. Compound food additives have gradually become mainstream in global food additives over the last decade because of their convenience, good effects and comprehensive functions. Examples include compound phosphate, compound sweeteners, compound baking powder, compound enzyme preparation, edible essence and broad-spectrum antimicrobial preservative. A large number of studies have shown that, compared with singular food additives, compound food additives can generate synergistic effects or derive some new effects, which can not only significantly reduce the usage amount of food additives, but also control product costs, reduce energy consumption, reduce pollution and shorten the development cycle of new products in food enterprises. They can also further improve food quality and increase the safety of food [20].

Therefore, compound food additives becoming a development trend is something that cannot be ignored in the future.

References

1 Jing Wang, Baoguo Sun. Food additives and food safety. *China Science Bulletin* (Chin Ver), 2013, 58: 2619–2625. [in Chinese]

2 Changzhu Wang, Jie Wu, Xiaoyu Gao. History, reality and future of food additives. *China Food Additives*, 2014, (1): 61–67. [in Chinese]

3 Qigen Tong. Food additives. *China Terminology*, 2011, (3): 57–59. [in Chinese]

4 Zhifei Zou, Haidan Lin, Rong Yi, *et al.* The codex and standards of food additives in China and application experiences. *Chinese Journal of Food Hygiene*, 2012, 24(4): 375–382. [in Chinese]

5 Xiaoyu Li, Maoqi Wang. The review of regulations and standards on food additives worldwide. *Chinese Journal of Food Hygiene*, 2004, 16(4): 308–312. [in Chinese].

6 Tonggang Zhao. Effects and safety control of food additives. *China Food Additives*, 2010, (3): 45–50. [in Chinese]

7 Baoguo Sun, Jing Wang. *Study on the Development Strategy of Food Materials Safety Control Technology*. Science Press, 2015. [in Chinese]

8 Beilei Pan. *Report on the Development of Food Industry and Technology of China in 2014*. China Light Industry Press, 2015. [in Chinese]

9 Liangli Yu, Shuo Wang, Baoguo Sun. *Food Safety Chemistry: Toxicant occurrence, analysis and mitigation*. CRC Press, 2015.

10 Baoguo Sun, Jing Wang, Jinyuan Sun. Perspectives on China Food Safety Problems. *Journal of Chinese Institute of Food Science and Technology*, 2013, 13(5): 1–5. [in Chinese]

11 Mingyan Wei, Junshi Chen. The return of 3.5 million tons of gutter oil has no evidence. *The Beijing News*, 2013-03-26(A20). [in Chinese]

12 The Associated Press. The Associated Press's review on the passing of the "Food Safety Law" in China. *Reference News*, 2009-03-01(8). [in Chinese]

13 Lin Gui. How to manage the food additives in foreign countries. *Agricultural Technology and Equipment*, 2011, 15: 76–77. [in Chinese]

14 Qiuer Chai. The management rules of food additives and status quo of safety standards in foreign countries. *Global Food Industry*, 2006, (3): 67–69. [in Chinese]

15 The new EU food additives list takes effect. *Food and Fermentation Industries*, 2013, (7): 170. [in Chinese]

16 Yun Cun. Food additives develop in the direction of function in foreign countries. *China Food Quality News*, 2004, 04: 007. [in Chinese]

17 Xin You. The development trend of food additives and functional ingredients. *China Food Additives*, 2008, (S1): 43–51. [in Chinese]

18 Xinquan Yang, Hongyu Tian, Zhaobo Chen, *et al.* Current status and development trend of research of food additives. *Current Biotechnology*, 2011, 1(5): 305–311. [in Chinese]

19 Qasim Chaudhry, Scotter Michael, Blackburn James *et al.* 2008. Applications and implications of nanotechnologies for the food sector. *Food Additives and Contaminants: Part A*, 25(3): 241–258.

20 Xiaohong Liu, Jianxiao Wan, Xin Wan. An. Effective Way to Guarantee Food Safety – Compound Food Additives. *The Food Industry*, 2010, (2): 98–100. [in Chinese]

13

Pesticide Residues

Xiongwu Qiao

Shanxi Academy of Agricultural Sciences, Taiyuan, China

13.1 Introduction

Pesticide residue in food has become one of the focal points of food safety in recent years, given the pivotal role of pesticide R&D and its application for positive promotion in the modern agriculture. Due to the specificity of China's agricultural production, the separated management of the small-scale family farms and the low level of professional expertise and mechanization, pesticide residues in food and farm products are very serious. China's management of pesticide residues in food is getting stronger as the world's food safety management upgrades. The key issues for reducing pesticide residues in food are as follows: residue source control, application of risk analysis principles throughout all the steps of pesticide management, including pesticide registration, pesticide production and marketing, pesticide application, knowledge when it comes to technology promotion and dissemination, cooperation between authorities, and industry and farmers. The trends in production management and operation scales of farming are getting better. The professionalism of plant production activities is being refined. Surveillance of the food chain continues to strengthen. All these have led to a higher level of food safety in regards to pesticide residues. This has built a foundation for China to manage pesticide residues on a dietary risk assessment basis, to strengthen risk communication and society multi-governance, and to control the pesticide residues in food below an acceptable level for health risk.

13.2 The Impact of Pesticide Residues on Food Safety

Pesticide input is the technical foundation of modern agriculture to achieve yield and efficiency. Putting chemical pesticides to use in the agricultural production process is determined by the pattern of the current world economy and social circumstances. There are lots of direct or indirect effects of using pesticides on food security, such as the balance between supply and demand of primary agricultural products, and especially the reduction of hunger in developing countries and social stability. However, the application of chemical pesticides also brought a series of significant negative impacts

Food Safety in China: Science, Technology, Management and Regulation, First Edition.
Edited by Joseph J. Jen and Junshi Chen.

on food safety. It is one of three urgent problems that need to be solved in the use of pesticides. The other two problems are environmental impacts and the resurgence induced by the resistance of pests and disease.

The intensity of pesticide use throughout the world differs because of the production modes, levels of technology, climate, and other factors. When the 1st edition of *The Pesticide Manual* [1] was published by the British Crop Protection Council (BCPC) in 1968, it only contained about 400 active ingredients; the number reached 1630 in 2012 in the 16th edition [2]. At this time, the registered pesticide active ingredients in China affect around 600 species and there are more than 20 000 formulations (including analogous products). In the twenty-first century, China is becoming the world's largest pesticide producer, user, and exporter. The production capacity increased stepwise from 200 000 tons at the end of the 1990s to more than three million tons in 2013.

The issue of pesticide residues differs from other risk factors in food safety. Compared to a variety of other pollutants and chemical risk factors, such as heavy metals, pesticide residues mainly result from their intended use during the crop production process. Compared to chemical risk factors such as food additives and mycotoxins, pesticide residues are employed in mostly natural environments, are poorly controlled, drastically variant, and are regarded as non-point source pollution. Pesticide residues also vary with the use of pesticides. As we enter the twenty-first century, pesticide product structure adjustment, strengthening of management of agricultural product quality and safety, training of farmers, and supervision of the production process all gradually mask the problem of acute poisoning from the attention of consumers and media. Instead, the focus is on pesticide residue standards, health risks that may be caused by pesticide residues, and the relevance between positive detection and food (farm product) quality. China's pesticide residue management is gradually emerging to bring in a legal system guided by risk analysis principles.

13.3 Past Events and Evolution of Pesticide Residue Issues: Changing Across the Centuries

Beginning in the 1980s and up to the start of this century, pesticide residues in China were mainly the persistent residues of organochlorine pesticides and the acute poisoning of organophosphate or carbamate insecticides or other similar pesticides. To solve the problem of pesticide residues, the focus is on food that can be "eaten without falling down," that is, no acute toxicity, especially control of acute intoxication caused by using highly toxic pesticides that weren't used according to the label or in violation of the rules of application to the food plant. To this end, China stopped the production and use of benzene hexachloride (BHC) and other organochlorine pesticides in the mid-1980s. Since then, pesticides classified as persistent organic pollutants (POPs) have gradually exited the market.

To reduce the impact of pesticide residues in food safety, the authorities have prohibited the use of dicofol, fenvalerate, and some other pesticides in tea cultivation. BHC and other organochlorine pesticides had been banned in China and highly toxic pesticides should not be used for vegetables, fruit trees, tea, and Chinese herbal medicines. The production of five highly toxic organophosphorus pesticides (methamidophos, parathion, methyl parathion, monocrotophos, and phosphamidon) was phased out.

Also, on June 28, 2002, the Ministry of Agriculture released Decree No. 17, announcing administrative regulations to withdraw or limit the use of these pesticides. It came with the production and certification of "pollution-free" agricultural products promoted by the Ministry of Agriculture, which managed to reduce pesticide residue pollution on food (agricultural) products from the production process.

Worldwide food security is entering a new era in the twenty-first century. A range of measures to ensure food safety was issued by international and individual countries' authorities, marked by the release of the EU "White Paper on Food Safety (2000)" [3], as well as the United States "Food Quality Protection Act (1996)" [4], and the "FDA Food Safety Modernization Law (2011)" [5]. A new age of pesticide residue management from farm to the table is coming. China's pesticide residue management has gradually been enhanced by international food safety progress,the outline of which is depicted by the following benchmark events.

On June 1, 2009, the Food Safety Law of the People's Republic of China [6] was announced. Compared with the former Food Hygiene Law, it had the following on pesticide residue management: (1) risk monitoring and risk assessment in food safety based on risk analysis principles was the scientific basis for formulating or revising the food safety standards and exercising food safety supervision and management, (2) pesticide residues and their test methods were the national mandatory standards in food safety, laying the foundation for food safety management, (3) producers of edible farm products were required to use pesticides and other agricultural inputs in accordance with the food safety standards and relevant state regulations. In addition, producers and the farmers' specialized cooperative economic organizations had to establish a production records system for edible agricultural products, (4) food ingredients, food additives, and food-related products that did not meet the food safety standards could not be sold or used, (5) production and proccessing of the food, in which the residual pesticide concentration exceeded the limits of the food safety standards were prohibited, (6) the national administration above the county level had to organizethe monitoring and control of food safety, and (7) producing, importing, or treating food, whereby the residual pesticide concentration exceeded the limits of the ood safety standards, against the rules, faced punishment.

Prior to the promulgation of the Food Safety Law, the PRC's Agricultural Product Quality Safety Law was implemented on November 1, 2006 [7]. Unlike the Food Safety Law, this Law focused on edible agricultural product quality and safety management during the traditional agricultural production process. They both supervise the risk factors, including pesticide residues, use of risk analysis principles, and establishing pesticide residue standards system in conformance with the requirements of the Food Safety Law, as well as other mandatory quality and safety standards for agricultural products aimed at the production process.

The Ministry of Agriculture established a quality and safety supervision bureau for agricultural products in 2008 to set agricultural product quality and safety standards, risk monitoring, risk assessment, and internal or external coordination of the Ministry. At the provincial (autonomous regions and municipalities) and county levels, special supervision institutions for agricultural product quality and safety were established. This led to a new stage where agricultural product quality and safety was monitored according to law. In 2007, the Ministry of Agriculture set up a national expert committee for risk assessment of quality and safety of agricultural products to undertake the task of conducting risk assessment of potential hazards that may affect the quality and safety of agricultural products. Meanwhile, the Ministry of Agriculture set up an expert group within the Ministry of Agriculture for agricultural product quality and safety in order to carry out related research into these areas and the activities of risk assessment or risk communication.

It is worth mentioning that, since the 1980s, China has had a pesticide registration and management system. The Ministry of Agriculture is responsible for pre-reviewing the proposed pesticide registration before production, to issue registration certificates for the products that meet the requirements, and to comprehensively supervise the pesticide products that will be put into use. Pesticide management in China has gradually embarked on the road of modern systematic management. In 1997, the State Council promulgated the Regulations on Pesticide Management [8] and made provisions for the registration, permission for production, production, marketing, and use of pesticides, basically in line with the requirements of contemporary industrialized administrations. Based on nearly 20 years' management practice, the Ministry of Agriculture released the Data Requirements for Pesticide Registration in 2001, and in 2007, the Minister of Agriculture issued the Provision for Data Requirements for Pesticide Registration as a replacement for the former [9]. According to this latest provision, residue chemistry data is required, which has become the one of five parts of registration data, along with the product chemistry, toxicology, biological activity, and environmental impact information. It has laid the foundation for the scientific management of pesticides and pesticide residue risk management. Applications for registration of all pesticides must provide field residue trials data on the targeted crop in the main producing areas in China to ensure that the usage mode of the approved pesticide is in line with the requirements of Good Agricultural Practice, so that the use of pesticides is in accordance with the product label, thus avoiding unacceptable dietary health risks in agricultural products. These residue chemistry data (also called supervised residue trials data) provide the necessary information for elaboration of appropriate pesticide maximum residue limits as national food safety standards at the same time. Since the early 1980s, supervised residue trials data has become the major data source for setting and revision of the National Food Safety Standard – Maximum Residue Limits for Pesticides in Food (GB 2763) [11].

According to the "Food Safety Law," the national health authority takes responsibility for organizing the food safety risk assessment and elaboration of national food safety standards. On this basis, the Ministry of Agriculture and the former Ministry of Health issued, in 2009, an advisory opinion on national food safety standard management related to pesticides and veterinary drug residues in food [12]. It determined that the Ministry of Agriculture will set up an expert working group for national standards for pesticide residues, to organize reviews, reports, and revisions of the standards, and the adopted standards should be issued by the Ministry of Health and the Ministry of Agriculture, according to the national food safety standards program. In 2010, the National Committee for Food Safety Standards and its subsidiary Sub-Committee on Pesticide Residues were formally established. Meanwhile, the National Committee on Pesticide Residue Standards was set up by the Ministry of Agriculture. Prior to 2010, according to the "Food Sanitation Law," the former Ministry of Health took charge of the elaboration of maximum residue limits (MRLs) for 136 pesticides, with 478 MRLs (GB 2763-2005). According to the Agricultural Products Quality

Safety Law, the Ministry of Agriculture issued 184 MRLs for 77 pesticides as sector standards.

After setting up of the National Committee on Pesticide Residue Standards, according to the MRL recombination plan made by the Committee and the Ministry of Agriculture, the Agricultural Product Quality and Safety Supervision Bureau of the Ministry of Agriculture developed a new pesticide MRL scheme, considering the pesticide registration reality in China, and factoring in the demands of agricultural production and consumption. As of 2014, 3650 MRL standards for pesticide residues for 387 pesticides have been integrated into GB 2763-2014. The residue analytical methods for pesticide residues in food has gradually been settled and integrated as mandatory national food safety standards as well. A suite of rules and regulations for pesticide residue standards that correspond to the food safety risk analysis principles has been established [13, 14]. Thus a national standard system for pesticide residues in food has basically been created.

To enhance the fundamental works on agricultural product quality and safety, in 2011, the Ministry of Agriculture approved the establishment of risk assessment laboratories for agricultural product quality and safety, namely, the production risk assessment laboratory in the China Academy of Agricultural Sciences, and regional risk assessment laboratories and risk assessment stations in the provinces (cities, districts). This constructed the backbone of a national risk assessment network, along with the expert committee of national risk assessment for the agricultural product quality and safety. Since their creation, risk assessment laboratories have carried out joint research and risk assessment of nationwide targeted pesticide residues, heavy metals, and other agricultural pollution incident, playing a strong supporting role in the related decision-making processes.

For implementation of the supervision obligations of the agricultural sector regarding quality and safety, given by the Quality and Safety Law for Agricultural Products, the Ministry of Agriculture set up testing facilities, with investment in human and material resources, in 2000. By 2009, there were 287 testing facilities above the county level for quality monitoring of agricultural products and agricultural inputs, of which, more than 80 facilities play as acted as ministerial centers. Routine monitoring of pesticide residues is one of the tasks of these detection institutions. The Ministry of Agriculture has continuously organized the routine monitoring of the agricultural product quality and safety. The routine monitoring results in 2013 (Table 13.1) have shown that the qualified rate of detection is above 98% [15].

The former Ministry of Health established the National Risk Assessment Center for Food Safety in 2011 to take on the risk assessment of food safety, the elaboration or revision of food safety standards, and the risk monitoring of food safety organized by the national health authorities. In addition, the national risk monitoring (provincial) sub-centers for food safety were established in the 32 provincial Centers for Disease Control (CDC). The Administrative Regulations for Risk Monitoring for Food Safety was issued jointly, in 2010, by the Ministry of Health, the Ministry of Industry and Information Technology, China's State Administration for Industry and Commerce, the National Bureau of Quality Inspection, and the State Food and Drug Administration of China. Simultaneously, the 2010 national food safety risk monitoring plan began, comprehensively supervizing varieties of food safety risk factors, including pesticide residues, in order to investigate the national food contamination levels and variation trends.

Table 13.1 The routine monitoring results of pesticide residues by the Ministry of Agriculture in 2013.

Products	Regions covered	No. of commodity classes	No. of pesticide residues tested	No. of samples	Rate of qualification
Vegetables	116 units in 14 provinces (autonomous regions and municipalities)	25	29, such as carbofuran	202	98.0%
Fruits	139 units in 13 provinces (autonomous regions and municipalities)	6	43, such as isocarbophos	139	98.6%
Tea	71 units in 7 provinces (autonomous regions and municipalities)	2	10, such as acephate	99	98.0%
Mushrooms	77 units in 8 provinces (autonomous regions and municipalities)	8	8, such as cypermethrin, and sulfur dioxide	100	99.0%

The plan also aims to find hidden risks, carry out preventive action, and provide scientific advice for risk assessment, the elaboration or revision of food safety standards, and the supervision of food safety. In 2013, according to the risk monitoring plan for national food safety, more than 40 kinds of pesticide residues that might be present in over 30 000 samples of vegetables, fruits, edible fungi and teas were tested [16]. In the same year, food contaminant observations in 2142 counties obtained 4.93 million monitoring data items. The monitoring results revealed some food safety risks due to environmental pollution, failed control of production processes, and the illegal use of prohibited substances. It also indicated te downward trends in food-borne diseases caused by chemical factors [17].

To summarize, food safety issues involving pesticide residues within China in recent years, can be placed in the following categories:

1) *The irrational use of pesticides caused residue violations.* China currently has 230 million family farms, a considerable number of which are managing a small business that covers less than one hectare. Although the government, the research and technology dissemination organizations, and the pesticide production and marketing enterprises have done a lot of work on the promotion and guidance of application techniques, there is often the phenomenon that the use of pesticides can't fully comply with the labeling requirements because of the large number of farmers, wide distribution, poor technological literacy of labor, and the low levels of applied technology and instruments. For example, overdosing exists, the frequency of use is more than recommended, and the pre-harvest interval has been shortened. All these have contributed to hidden risks of pesticide residues exceeding legal limits. Therefore, the low level of intensification and the small scale of farming, leading directly to low

levels of expertise and pesticide equipment, are the most significant factors affecting the pesticide residue problem. The situation that there is an excess of parathyroid pesticide residues in the fruit and vegetable products is mostly due to these issues.

2) *Illegal use of pesticides and illegal components in a pesticide formulation can cause excessive residues.* In principle, the law requires the user to specify the crops that the pesticide products apply to, when registering the pesticides, and the corresponding maximum residue limits are also worked out based on the residue trials data of the crops listed. However, in the actual production process, since there is no effective guidance and supervision, the pesticide is often used on unregistered crops. The result is that, due to the absence of development of appropriate MRLs or registration, the low standard values of residue limits on farm products can lead to cases of detection or exceeding of limits. In addition, some undeclared ingredients have been added illegally to the pesticide products intended to increase efficacy and reduce costs. The detection of phorate residue in vegetable products is just such a case.
3) *Erroneous judgment caused pesticide residue events.* On account of testing and monitoring behavior that did not meet the technical requirements, there have been erroneous judgments of excessive pesticide residues in recent years. The most typical is the "poisonous berry event" in April 2015. At first, media reported that eight random samples of strawberries purchased during harvest time were all detected to contain the acetochlor pesticide. After the incident, local governments organized special sample monitoring and the detection of 175 samples covering the main production origin did not show any acetochlor. Nevertheless, the inaccurate information about "poisonous berries" circulated amongst the media and has led to financial losses of more than twenty million yuan to Beijing growers.
4) *Knowledge and understanding of pesticide residues.* The use of pesticide, as a production input, inevitably brings about the problem of residues and the elimination of dietary health risks caused by the pesticide residues is the core of the standards system and the management of pesticide residues. At present, consumers understand the pesticide residue problem mostly through the mass media. How to avoid the one-sided emphasis and the excessive or thoughtless estimates of the pesticide residues issue is a hard nut to crack. For example, it was reported that hundreds of pesticide residues could be detected in the field water, soil, and air during the farm production phase. In fact, this is a normal phenomenon. There are more than 600 kinds of currently registered applications of pesticides in China, so after use, they might be scattered in the field environment through runoff and drift, but the concentration can't be too high. The agricultural environment has the purification capacity to digest most pesticide residues, so that there is no accumulation in farm environments from the continuous use of pesticides for years. In addition, the awareness of pesticide risks to health may be a more specialized and complex issue. This can be understood by the evocable effect of the different conclusions that were drawn by the two advisory bodies (JMPR/IARC) of the World Health Organization about the toxicity of herbicide glyphosate in 2015. It is obvious that, to make the consumers and media accurately, qualitatively, and quantitatively understand the issue of pesticide residues under the current management system for food safety, a lot of work must be done on scientific assessment and risk communication.
5) *The cognitive problems of the existing food safety systems.* Modern food safety management based on risk analysis principles has been written into the "Food Safety

Law," but the understanding by different stakeholder groups of risk assessment has a considerable gap. The focus of the issue is to correctly understand the relationship between risks and hazards. Oftentimes, the control measures for food safety based on acceptable risk are not accepted by all the stakeholders. Sometimes, the related professional practitioners do not agree with one another. We sometimes see a physician consulted in order to explain the hazards of pesticides on various organs, so that the audience can appreciate that eating foods containing pesticide residues can cause serious unacceptable consequences, such as carcinogenicity. This is also a risk communication problem.

13.3.1 The Main Direction of Scientific Research

Comprehensive research on pesticide residues in China began in the 1970s, when the attention of studies was on residual organochlorine pesticides in the environment and agricultural products. During the twenty-first century, China's research on pesticide residues has become more of a series of studies to coordinate with national pesticide management and explore its involvement in food safety issues. Because pesticides are a kind of agricultural input that needs to have market access qualification, most of the research and other related studies on pesticide residues has been conducted during the development of a pesticide in the industrial sector. Most of the data obtained is used to meet the demands of the government registration administration, thanks to industrial countries that help to improve pesticide management and the requirements for food safety. Also, thanks to risk communication and the publicly transparent systems of these management institutions, the vast majority of pesticide residue data (related to product chemistry, toxicology, the metabolic transformation behavior in plants, animals and the environment, registration residues trials, the residue behavior and the residue detection methods during the processing and feed feeding, etc.) are open in the form of a detailed special report, such as various reports from FAO/WHO Joint Meeting of Experts on Pesticide Residues (JMPR), various pesticide evaluation reports of the United States Environmental Protection Agency (USEPA), the pesticide evaluation reports of the European Food Safety Authority (EFSA), and so on. As there are fewer innovative pesticides initiated in China, the original studies on pesticide residues in/on food are generally limited to the test results of supervised residue trials that are required for pesticide registration in China, and a small number of risk assessment conclusions on dietary exposure assessment [18–22].

Over the past decade, other noteworthy progress in pesticide residues research involving food safety has been in establishing the system of pesticide residue standards and introducing the risk assessment mechanism. With the establishment of the National Committee on Pesticide Residue Standards, through the implementation of major projects for national food safety, a number of guidance documents supporting the pesticide residues standard system have been studied and formulated [13], such as the Guidelines for Establishing the Pesticide Maximum Residue Limits in Agricultural Products and Food, the Guideline for the Risk Assessment of Pesticide Residues in Agricultural Products and Food, the Crop Classification for Establishment of Pesticide Maximum Residue Limits, the Guideline for Drafting Pesticide Residue Detection Methods as the National Food Safety Standards, the Guidance for Setting the Acceptable Daily Intake of Pesticide, and so forth. Plus, the earlier ministerial standards established by the Ministry of Agriculture, Test Guidelines for Pesticide Residue Trials (NY/T 788-2004) [10], the Good Laboratory Practice for Pesticide Residue Testing (NY/T 1493-2007) [14], and others, the document system for pesticide residue management and the related food safety standards in China was formed. Risk analysis principles and risk assessment has drawn the recent attention of the national authorities and academic circles. For studies on the risk assessment of pesticide residues at present, China is still in the understanding and the digestion phase [23, 24]. Although scholars have noted risk assessment and its basic concepts and methods, they are suffering from a lack of theory and experience coupled with insufficient high-quality data on quantity. Following modern risk analysis principles, there are also some elements missing in order to meet the requirements for reliable risk management of pesticide residues for food safety, such as short-term dietary exposure assessment during the process of MRL elaboration [25]. To meet the scientific requirements of risk assessment, such as systematics, comprehensiveness, and accuracy, there is still quite a lot of work to do. The key is the lack and imperfection of exposure assessment data and an evaluation system that needs to be improved in serviceability. To try to improve the quality and representativeness of the pesticide residue trials data, the dietary consumption data has become the focus of future research.

In terms of international cooperation and information exchange, there are two events involving pesticide residues in the last ten years that should be mentioned.

One is the initiation of an official review of SPS notifications since 2005. After China joined the WTO in 2001, in accordance with the demands of the SPS agreements, the member states should notify the WHO of the status of their sanitary and phytosanitary measures, such as the maximum levels of pesticide residues in food, at least three months before coming into force. Members of the WTO could review the impact on maintaining SPS principals and on international trade in food. In 2004, the Ministry of Agriculture arranged the official review of pesticide-related SPS notifications. Since 2005, it has been first to review and feedback a large number of notifications presented by WTO members concerning pesticide residue standards, pesticide production policies, production and trade measures [26, 27]. The work of reviewing SPS notifications involving pesticides and pesticide residues should be the start of China merging research on pesticide residues and its management into the modern food safety system. By learning the methods and management experience of industrialized countries, the importance of risk assessment for pesticide residues was truly understand. It not only provided a channel to avoid possible international trade friction, through negotiation and communication under the framework of SPS, but also provided a historic opportunity for use as a reference to establish China's standards system on pesticide residues in food, and for Chinese food safety management relating to pesticide residues. Later, the Chinese SPS notification of the development of pesticide maximum residue limits and other measures related to pesticide management have also provided a first communication channel for China's implementation of WTO obligations, and exchange or consultation with major trading partners in this area.

Another issue was taking over as the host country of the Codex Committee on Pesticide Residues (CCPR) in 2006. In the 28th annual meeting of the Codex Alimentarius Commission (CAC), China was designated to be the host country of the CCPR, and to chair the committee from its 37th annual meeting, something that has been conducted by the Netherlands for 41 years since 1966. At the same time, China also took over the chair of the Codex Committee on Food Additives (CCFA) from the Netherlands [28].

As a new host country, China designated the Ministry of Agriculture to establish the secretariat of the CCPR, appointed the Chairperson of the Committee, and organized the annual meeting of the CCPR under the guidance of the CAC secretariat. Until April 2016, the CCPR has held ten annual meetings in China. During this period, more than 200 delegates from about 60 member states and observer organizations have attended yearly. Based on the recommendation of the FAO/WHO Joint Experts Meeting on Pesticide Residues (JMPR), the CCPR annually accepted more than 300 pesticide MRLs in food and pushed it through to CAC for adoption as Codex MRLs. The standards that were newly developed or revised become the arbitration standards in international food trade designated by the WTO/SPS agreement. The CCPR also developed the risk assessment policy and techniques on pesticide residues and a series of related documents, which became the decision reference of the JMPR and member states for the risk assessment of pesticide residues and to develop residue standards. Becoming the host of the CCPR is an outstanding contribution by China to the international community in the arena of pesticide residue management in food safety. The smooth progress of work has gained the recognition and praise of the FAO/WHO, the member states and the observer organizations. In particular, as a developing country and a major nation for pesticide production, consumption, and export, the influence of China drew obvious international attention. Taking the opportunity at the CCPR annual meetings, various participants in the world organized countless regional, bilateral, and expert communications and information exchanges, which played a unique role in the promotion of international risk assessment and management of pesticide residues. China, as the host country, benefits first.

The international cooperation and communication in the field of pesticide residue management also included the following: (a) In the "Food Safety Cooperation Forum," of which the presidency is shared by China and Australia in the Asia-Pacific Economic Cooperation (APEC), the harmonization of standards on pesticide maximum residue limits has become one of the primary focuses of the various APEC economies in recent years. (2) The foreign aid training program of the Ministry of Commerce on food safety, undertaken by the China Research Institute of Food and Fermentation, has trained nearly 2000 food safety officials and technical personnel from 123 developing countries since 2005, one of the elements is pesticide residues and pesticide management. (3) The technical and managerial capacity-building projects of FAO on pesticide residues. (4) The international bilateral exchanges of management and techniques on pesticide residues (Sino-USA, Sino-EU, etc.) (5) The Hong Kong joint expert consultancy activities, "the regulation of pesticide residues in food," organized by the General Administration of Quality Supervision, Inspection, and Quarantine of the People's Republic of China (AQSIQ), turned into a model of cooperation in pesticide residue management in regional affairs and among the economies.

13.4 The Current Status of Pesticide Residues in Food Safety and Management Measures

13.4.1 Revision of the Food Safety Law

The newly revised "Food Safety Law," which won approval during the 14th meeting of the 12th standing committee of the National People's Congress on April 24, 2015, was implemented from October 1, 2015 [29]. Relating to pesticide residues, the new law stresses once again that it is prohibited to use highly toxic pesticides on vegetables, fruits, tea leaves, cultivation of herbal medicines, and other crops, as the state specifies. However, the separation of risk monitoring and risk assessment of edible agricultural products from that of the downstream food products reflects the differences in the system and is known in modern risk management of food safety among the legislature, the government, and the industry.

13.4.2 Amendment of the Pesticide Management Regulations

In order to adapt to changes in the national industrial management and operation pattern of agricultural production, in 2007 the Legislative Affairs Office of the State Council and the Ministry of Agriculture started to revise the 1997 version of the pesticide management regulations. The revised draft was intended to cancel the provisional registration of pesticides and to change to a pesticide business license system in terms of the pesticide marketing regulations. It also inserted the requirement for a pesticide traceability system, encouraging the use of low toxicity biological pesticides, and strengthening the obligation of a business to deliver guidance on pesticide use. It also sought to cancel the provisional registration of pesticide, which allows marketing of a pesticide product without submission of the residue data for dietary risk assessment and MRL elaboration prior to the application for registration. The residue chemistry data for a pesticide product would now need to be committed during initial registration. This would reduce the risk of residual contamination, even with excessive residue from the agro-products. Strengthening the pesticide marketing management would regulate pesticide sales and technical service, improve the level of pesticide application technology, and supervision management, especially, and adapt to the intensive, professional, and improved change in the current cultivation system. It is hoped to reduce pesticide residue pollution, and promote the level of quality and safety of agricultural products.

13.4.3 The Pesticide Reduction Plan

Under pressure from the increasing demand of food, Chinese agriculture is on the way to a higher level of intensification. What is remarkable is the increasing trends for the input of fertilizer and pesticide. However, due to the agricultural market environment, family decentralized management, and poor training of the agricultural labor force, space to improve the level of agricultural technology is limited. All these build a constraint on the quality and safety of agricultural products. Over the years, on account of the expanding crop acreage and increasing difficulty of pest control and prevention, the use of pesticides overall is on an upward trend. According to statistics, from 2012–2014, the average annual pesticide use on crop pest control and prevention reached 311 000 tons. Compared to the 2009–2011 period, there was an increase of 9.2% (see comparative data in 2013 in Table 13.2).

The extensive use of pesticides, the low level of pesticide application technology, and the poor quality of pesticide spreading machinery, has resulted in increasing production costs, high residue levels in agricultural products, crop phytotoxicity, and environmental pollution. In 2015, the Ministry of Agriculture prepared and issued the Zero-Growth Action Plan for pesticide use for the following five years until 2020 [31]. In the same year,

Table 13.2 Pesticide use in China in 2013 [30].

Pesticide Group	Amount used (thousand tons)	Percentage (%)	Varieties over ten thousand tons	Other main varieties
Insecticide	130	39.4	DDVP, Chlorpyrifos	Phoxim, bisultap, lime sulfur, acephate, monosultap, omethoate, triazophos, dimethoate, buprofezin, imidacloprid, malathion, profenofos, pymetrozine, isocarbophos, propargite, phorate, pyridaben, etc.
Fungicide	80	24.2	Bluestone\ Carbendazim	Thiophanate-methyl, chlorothalonil, tricyclazole, validamycin, triadimefon, FuMei class, isoprothiolane, copper hydroxide, metalaxyl, fenaminosulf, fosetyl-aluminum, prochloraz, oxadixyl, tebuconzole, etc.
Herbicide	120	36.3	Glyphosate\ Acetochlor\ Atrazine	Butachlor, paraquat, 2, 4-d butyl ester, bentazone, metolachlor, trifluralin, MCPA, fomesafen, quinclorac, etc.
Rodenticide	0.1	–	–	Diphacinone-sodium, bromadiolone, brodifacoum, warfarin, coumatetralyl
Plant Growth Regulator	<6	–	–	Paclobutrazol, uniconazole, gibberellic acid, ethephon, mepiquat chloride, brassinolide
Total	330	99.9		

the Ministry of Agriculture, with the National Development and Reform Commission, the Ministry of Science, the Ministry of Finance, the Ministry of Land Resources, the Ministry of Environmental Protection, the Ministry of Water Resources, and the State Forestry Administration, jointly issued the "National Sustainable Agricultural Development Plan (2015–2030)" [32]. It aims to overcome the current contradiction in the crop industry between agricultural production and environment protection, improve food quality (edible agricultural products), and achieve a sustainable effective supply of high-quality agricultural products. In the next few years, in accordance with the guidance for changing the agricultural development pattern, control of agricultural non-point source pollution, cost savings and an increase in effective agriculture, the phasing out of highly toxic pesticides, reduction of the overall risk of relying on new agricultural business entities, vigorous promotion of large-scale pest control and prevention, and professional services, guidance of farmers to use pesticides scientifically in a rational way, and improvement of pesticide utilization will all be achieved. The measures are expected to gradually realize the goal of control of total pesticide use at nil growth levels compared to the average usage levels between 2012 and 2014.

13.3.4 National Standards System Has Gradually Improved the Basis for Management of Pesticide Residues in Food

Until 2014, the 3650 pesticide MRLs for 387 kinds of pesticides have been elaborated on (GB 2763-2014). With the expansion of the variety and application scope of registered pesticides, new MRLs are constantly being set up and the work of adopting the MRLs set by the Codex also continues. For some so-called "minor crops," there is no pesticide manufacturer willing to register their pesticide products, but there is still a demand for chemical protection. Competent administrative authorities for agriculture are putting resources into the supplemental registration and the elaboration of corresponding MRLs, aimed to ensure food safety. The latest draft catalog for MRLs in food (draft GB 2763-2015) includes 4139 MRLs for 433 kinds of pesticide. According to the "13th Five Year Plan" by the Ministry of Agriculture, by 2020, the total number of MRLs will reach more than 10 000. The target for the national management of pesticide residues is to develop appropriate MRLs for all pesticides registered for use in China, while meeting the demand for food imports and other food safety supervision requirements of the market as well.

The government of the Hong Kong special administrative region has been one step ahead with regard to residue standards elaboration. The "Regulations for Pesticide Residues in Food" [33] came into effect on August 1st, 2014, and listed 7083 MRLs for 360 kinds of pesticide in food, which basically covered the food in the Hong Kong market and linked up with the standards in the major food producing countries. For nearly a year, the monitoring of pesticide residues in fruits and vegetables from import, wholesale, and retail markets indicated that the excess residue rate is less than 0.4%.

International and regional cooperation and information exchanges in the field of pesticide residues continues. China is hosting the Codex Committee on Pesticide Residues for the tenth year. Chinese experts continue to participate in the FAO/WHO Joint Expert Meeting on Pesticide Residues, not only in terms of residue chemistry, but also toxicology [34]. China began to take the initiative to provide data to support the Codex Alimentarius Commission in developing Codex MRLs with Chinese regional characteristics. The "APEC Food Safety Cooperation Forum," chaired by China and Australia, made substantial steps to promote trade. At present, as a matter of priority, a pilot for MRL harmonization on wine and mango (tropical fruit) is being considered. Food safety technology and management capacity-building projects, including pesticide residues and pesticide management, for regions and developing countries on behalf of national and international organizations is ongoing. The technology and management exchange and cooperation concerning pesticide residues between mainland China, Hong Kong, Macao, and Taiwan is having a positive impact on bilateral trade in agricultural products as well.

13.5 The Future of Risk Management for Pesticide Residues in Foods

Looking back on the influence of pesticide residues on food safety and the progress of risk management over the past decade, we are pleased to see that, as one of the food safety risk factors, the evaluation of the health risks of pesticide residues on consumers is becoming increasingly scientific and rational. While acknowledging the inevitable stages of pesticide residue control, to make great efforts to reduce the number of pesticide residue types, to lower pesticide residue levels, and to strictly control pesticide residues to below acceptable levels, has gradually become the consensus among consumers, the media, the scientific community, and the government. The approach to pesticide residue management is maturing and strengthening from day to day. However, food safety requires societal multi-governance from farm to table, but pesticide residues need fundamentally to be treated at the source. Only the scientific and rational use of pesticides can reduce the health risks of pesticide residues and allow them to reach a safe level. Based on this consideration, the management of pesticide residues still has much to do:

1) *Further implementation of risk analysis principles in food safety, and promotion of a risk assessment system for pesticide residues based on science.* How to pragmatically build a risk management mechanism and organization system for pesticide residues should be an imperative for China to resolve the risk management of pesticide residues. Especially in light of the special nature of pesticide residues, improving the risk assessment system should take the highest priority. The FAO/WHO recommend the application of guidance on risk analysis in food safety at a national level [35]. However, the actual implementation must have certain pre-conditions. Risk assessment can't be simply solved by a given formula such as "Risk is equal to the hazard multiplied by exposure." More in-depth and specific work needs to be done. For example, refining the issue of supervised residue trials by asking for more than is practiced now, in accordance with the number of crops that the pesticides are registered to be used on, the importance of the crops for the national food supply, and the dietary importance of the food; establishing a dietary consumption database for different regions and different age groups within the country, establishing a distribution-based probabilistic analysis method, employing and improving the toxicological reference values (ADI, ARfD, etc.) to be used for risk assessment of pesticide residues in the whole process, and so on. Through these series of measures data quality will improve, uncertainty will be reduced, the recommended standards and adopted management measures will better reflect the actual production situation, and there will be a higher operational ability.
2) *Strengthen the management of pesticides and pesticide residues before, during, and after production in strict accordance with the " Agricultural Product Quality and Safety Law" and the "Food Safety Law."* Making food safe needs not only supervision of the market, but also control of the production process. The latter concept is more suitable for the case of pesticide residues. Production process control is more important under the current agricultural production and consumption conditions in China. If China wants to achieve a pesticide reduction plan, we should start from the adjustment of pesticide registration and the structure of the pesticide products, then strengthen the supervision and technical guidance of pesticide applications. In the coming years, the intensive, large-scale, and professional management of agricultural production in China will become the key to reducing pesticide volume or maintaining the zero growth of pesticide use in China and will also be the main pathway to significantly reducing pesticide residue pollution and improving the safety level of agricultural products.

3) *Improving the standards system for pesticide residues to achieve full coverage of production, marketing, and consumption of all foods (including imported food).* At present, there are only 3650 national mandatory MRLs for 387 registered pesticides in China. Many pesticides used on crops for pest control are neither registered nor are there MRLs available. Compared to the tens of thousands of MRLs in industrialized countries in Europe and North America, it's obviously not enough. China is a main food (agricultural products) importer and exporter. Without the necessary MRLs, comparable to that of industrialized countries, China will clearly not only increase the health risks to consumers, but also seriously block international and domestic food trade. It is the time to resolve the lack of of MRLs for food safety and trade.
4) *Completing and strengthening food safety supervision and improving monitoring ability, gaining feedback, and guiding agricultural production, food production, and marketing.* The "Food Safety Law" and the " Agricultural Product Quality and Safety Law" both stipulate that relevant government institutions must organize the implementation of a risk monitoring plan. However, the current model of separating the agriculture sector and other sectors of domestic and imported food safety management is not reasonable. There should be a complete food chain, the information and feedback from which should be integrated to give the full risk monitoring picture in order to guide production and marketing. In recent years, different sectors in China have established their technical hardware to be world class. But, due to the separation mechanism, every sector works only on its own responsibilities, leading to a serious waste of resources. They always act in their own way and stick with repetition at a low level of technology and capability. So far, a monitoring technology system with unified methodology and wide coverage of the target has not been established. For example, the recent national or sector risk monitoring plans include only dozens of pesticide residues. Compared to the residue monitoring of 300–400 kinds of pesticides in industrialized countries, there is still a considerable way to go.
5) *Strengthening risk communication for food safety relating to pesticide residues.* Efforts should be made to allow consumers, the media, risk managers, and risk assessors to better acknowledge and understand food safety issues associated with pesticide residues in a timely manner, knowing the measures to respond to the risks of pesticide residues, and grasping them well enough to put into practice. The actual food safety situation in China and its capacity have significantly improved, whether compared to other foreign countries, or compared to the past. But the problem is that food production and the consumption pattern in China have changed tremendously. The length of the food chain has been extended far beyond those years when urban consumers bought primary agricultural products in government stores and cooked for their families themselves. The structure and the mode of food consumption in rural areas have also undergone a corresponding upgrade. Coupled with the changes in agricultural production patterns, particularly in intensified management and in the current market environment of low economic efficiency, food safety issues start to get complicated from the beginning of agricultural production. This sort of change not only puts forward higher requirements for food safety management, but also generates new problems, which are difficult to understand for consumers, producers, the mass media, and other stakeholders. This also explains why risk communication is one of the three components of risk analysis. Popularization of science,

public transparency, and legalization should be an important part of the many measures needed to do a good job in risk communication.

References

1 British Crop Protection Council, 1968, *Pesticide Manual: Basic Information on the Chemicals used as Active Components of Pesticides*, Martin, H. (ed.). The British Crop Protection Council, Farnham, England, 464 pp.

2 British Crop Protection Council, 2012, *The Pesticide Manual: A World Compendium, 16th edition*, McBean, C. (ed.). The British Crop Protection Council, Farnham, England, 1440 pp.

3 The European Comission, 2000, White Paper on Food Safety COM (1999) 719, Brussels, 12 January 2000, http://ec.europa.eu/dgs/health_consumer/library/pub/pub06_en.pdf (accessed October 2016).

4 US Public Law, 1996, Food Quality Protection Act (FQPA, PL 104-170), H.R. 1627: House Reports: No. 104–669, Pt. 1 (Comm. on Agriculture) and Pt. 2 (Comm. on Commerce). http://www.epa.gov/opp00001/regulating/laws/fqpa/gpogate.pdf (accessed October 2016).

5 US Public Law, 2011, FDA Food Safety Modernization Act (FDA FSMA, PL 111-353), H.R. 2571, http://www.fda.gov/Food/GuidanceRegulation/FSMA/ (accessed October 2016).

6 The Standing Committee of the National People's Congress, 2009, The Food Safety Law of the People's Republic of China, The Legal Office of the State Council, http://www.chinalaw.gov.cn/article/fgkd/xfg/fl/200903/20090300129044.shtml (accessed October 2016) [in Chinese].

7 The Standing Committee of the National People's Congress, 2006, The Law of Produce Quality and Safety of the People's Republic of China, The Legal Office of the State Council, http://www.chinalaw.gov.cn/article/fgkd/xfg/fl/200605/20060500051402.shtml (accessed October 2016) [in Chinese].

8 The State Council of the People's Republic of China, 2002, No. 326 of the Decree of the State Council of the People's Republic of China: The State Council's Decision on Modifying Pesticide Management Regulations, The Gazette of the State Council of the People's Republic of China, no. 1 (cumulative no. 1036) http://www.gov.cn/gongbao/content/2002/content_61560.htm (accessed October 2016) [in Chinese].

9 The Ministry of Agriculture, 2007, No.10 of the Decree of the Ministry of Agriculture: Data Requirement for Pesticide Registration. http://www.moa.gov.cn/govpublic/CYZCFGS/201006/t20100606_1532747.htm (accessed October 2016) [in Chinese].

10 Ministry of Agriculture, 2004, The Sector Standard of the Ministry of Agriculture of the People's Republic of China: Guideline on Pesticide Residue Trials, NY/T 788-2004, China Agriculture Press, Beijing [in Chinese].

11 The State Commission of Health and Family Planning, The Ministry of Agriculture, 2014, The National Standard of the People's Republic of China on Food Safety: The Pesticide Maximum Residue Limits in Food (GB 2763-2014), China Agriculture Press, Beijing, pp. 213 [in Chinese].

12 The Ministry of Health and The Ministry of Agriculture, 2009, The Consultation Results on the Management of the Standards of Pesticide Residues and Veterinary Drug

Residues in Food (Letter by WeiBanJianDu (200) no. 828). http://www.foodmate.net/law/shipin/165565.html (accessed October 2016) [in Chinese].

13 The Secretariat of the Commission of National Food Safety Standards, 2013, Procedure Manual for Elaboration of National Food Safety Standards, China Quality Inspection Press, China Standard Press, Beijing, pp. 174 [in Chinese].

14 The Ministry of Agriculture, 2008, The Sector Standard of the Ministry of Agriculture of the People's Republic of China: Good Laboratory Practices for pesticide Residue Trials, NY/T 1493-2007, China Agriculture Press, Beijing, pp. 13 [in Chinese].

15 The Bureau of Quality and Safety Supervision for Agro-Products, The Ministry of Agriculture, 2014, Notification of the Monitoring Results of the National Targeted Supervision of Safety for Agro-Products in 2013 Announced by the General Office of the Ministry of Agriculture. http://www.caqs.gov.cn/News/Detail/?ListName=%E5%86%9C%E4%B8%9A%E8%B4%A8%E6%A3%80%E4%B8%93%E6%A0%8F~01%E9%80%9A%E7%9F%A5%E6%96%87%E4%BB%B6&UserKey=PLW2BJLDCR7TBF2T (accessed October 2016) [in Chinese].

16 The State Commission of Health and Family Planning, 2012, The Announcement of the National Risk Monitoring Plan for Food Safety in 2013 (Document WeiBanJianDu (2012) no. 131) [in Chinese].

17 The State Commission of Health and Family Planning, 2014, The Progress Report on Food Safety Standards Elaboration and Monitoring and Evaluation Works. http://www.moh.gov.cn/sps/s3594/201406/8a7e0c4656a242bfb33813a6966d90bc.shtml (accessed October 2016) [in Chinese].

18 Yuan L., Li J., Mo H., Guo B., Wang H., 2010, The residues and degradation dynamics of abamectin in baby bokchoi and common head cabbage under the condition of specification residue trials, *Chinese Journal of Pesticide Science*, 2010, 12(2):185–189 [in Chinese].

19 Yang G., Chen C., Wang Q., Zhao H., Zhang Z., Cai Z., Qian Y., 2015, Risk assessment for combined exposure of multi-residue of pesticides, *Chinese Journal of Pesticide Science*, 17 (2): 119–127 [in Chinese].

20 Zhao E., Zhu X., Zheng Z., Jia C., Yu P., He M., 2015, The residue behavior of kresoxim-methyl and procymidone in the strawberry in greenhouse and their risk assessment of dietary intake, *Chinese Journal of Pesticide Science*, 17 (1): 75–82 [in Chinese].

21 Wu J., Wang H., Wu X., Zhao J., Yang N., 2012, Determination of azoxystrobin residue in Panax ginseng and Panax quinquefolium and dietary intake risk assessment, *Chinese Journal of Pesticide Science*, 14(1): 67–73 [in Chinese].

22 Yuan Y, Zhang Z, Ye Z, 2011, Effects of simulated processing on pesticide residues in spinach and its dietary exposure assessment, *Chinese Journal of Pesticide Science*, 13(2): 186–191 [in Chinese]

23 Institute of Quality Standards and Testing Technology for Agro-Products, Chinese Academy of Agricultural Science, 2007, The Risk Assessment of the Quality and Safety of Agricultural Products: Principle, Method and Application. Standards Press of China, Beijing, pp. 530 [in Chinese].

24 Chen X., Deng N. (eds.), 2004, *Study on China's National Food Safety Strategy*. Chemical Industry Press, Beijing, pp. 930 [in Chinese].

25 Sun R., Qiao X., Qin S., 2015, Study on acute dietary exposure assessment needs for Chinese pesticide MRLs in food, *Chinese Journal of Pesticide Science*, 17(5): 544–554 [in Chinese].

26 Shan W., Jian Q. (eds.), 2011, Analysis and Research on the International Technical Measures for Trade Concerning Pesticides, Volume 1 (2005–2006), China Agricultural University Press, Beijing [in Chinese].

27 Shan W., Jian Q. (eds.), 2011, Analysis and Research on the International Technical Measures for Trade Concerning Pesticides, Volume 2 (2007–2008), China Agricultural University Press, Beijing [in Chinese].

28 Codex Alimentarius Commission, 2006, Report of the Twenty-ninth Session of The Codex Alimentarius Commission. http://www.codexalimentarius.org/download/report/662/al29_41e.pdf (accessed October 2016).

29 The Standing Committee of the National People's Congress, 2015, The Food Safety Law of the People's Republic of China. The website of the Central People's Government of the PRC, http://www.gov.cn/zhengce/2015-04/25/content_2853643.htm (accessed October 2016) [in Chinese].

30 Li W., Huang H., Li H., 2015, The present regulating situations and the countermeasures of the pesticide use in China, *Pesticide Science and Administration*, 36(8) :1–5 [in Chinese].

31 Ministry of Agriculture, 2015, The Notification by the Ministry of Agriculture About the Issuance of "The Action Plan for Nil Growth of Fertilizer Use Till 2020" and "The Action Plan for Zero Growth of Pesticide Use Till 2020" http://www.moa.gov.cn/zwllm/tzgg/tz/201503/t20150318_4444765.htm (accessed October 2016) [in Chinese].

32 Ministry of Agriculture, The National Development and Reform Commission, Ministry of Science and Technology, Ministry of Finance, Ministry of Land and Resources, Ministry of Environmental Protection, Ministry of Water Resources and the State Forestry Administration, 2015, The Notification of the Issuance of "The National Framework of Sustainable Development in Agriculture (2015–2030)". http://www.moa.gov.cn/zwllm/zxfb/201505/t20150527_4620018.htm (accessed October 2016) [in Chinese].

33 Government of Hong Kong Special Administrative Region, 2012, The Regulations on Pesticide Residues in Food, *The Gazette of the Government of Hong Kong Special Administrative Region*, No. 18 Vol. 16 - Legal Supplement No. 2(04/05/2012) http://www.gld.gov.hk/egazette/english/gazette/pdf.php?extra=0&year=2012&month=05&day=04&vol=16&no=18&gn=&type=2&id=73 (accessed October 2016).

34 FAO/WHO, 2015, Pesticide Residues in Food 2014: Report of the Joint FAO/WHO Meeting on Pesticide Residues. FAO Plant Production and Protection Paper 221.

35 WHO/FAO, 2006, Food Safety Risk Analysis: A Guide for National Food Safety Authorities, FAO Food and Nutrition Paper No. 87.

14

Veterinary Drug Residues in China

Zhenling Zeng[1], Fan Yang[2] and Liqi Wang[3]

[1] *South China Agricultural University, Guangzhou, China*
[2] *Henan University of Science and Technology, Louyang, China*
[3] *Jiangxi Agricultural University, Nanchang, China*

14.1 Introduction

14.1.1 Definition of Veterinary Drug Residues

Veterinary drugs, which treat animal disease, maintain herd health, promote growth, or improve meat quality by reducing fat and increasing lean meat yield are critically needed to meet the challenge of providing adequate amounts of animal-derived foods for the growing world population [1]. But the benefit of the improved production from the use of veterinary drugs is not obtained without risk – the risk associated with drug residues that remain in the animal-derived foods (such as edible tissue, eggs, and milk, etc.) [2]. Veterinary drug residues are the very small amounts of veterinary medicines that can remain in animal products and therefore make their way into the food chain. These include any degradation metabolites, which are the result of the medicine breaking down into its component parts [3]. If animal drugs were not absorbed or were metabolized to harmless products, there would be no concern. Unfortunately, this is not usually the case.

Antimicrobial drugs are the most widely used in veterinary clinics, and include antibiotics and chemically synthesized antibacterial drugs. Antibiotics used in China include eight categories and a total of 56 drugs, such as β-lactams, aminoglycosides, tetracyclines, and so on. The synthetic or semi-synthetic antibacterial drugs consist of three categories and a total of 22 drugs, including sulfonamides, fluoroquinolones, and the others that are permitted as animal feed additives.

By definition, a veterinary drug residue is either the parent compound or a metabolite of the drug that may accumulate, deposit, or otherwise be stored within the cells, tissues, organs, or edible products (e.g. milk, eggs) of an animal after its use. Residues can also result from unintentional administration of drugs, or food additives. Finally, accidental exposure to chemicals in the environment can also result in tissue residues.

In both human medical and companion-animal veterinary practice, the main concern in drug selection and application is the therapeutic effect. If doses of greater than recommended levels were administered, the potential toxicity is of concern. While this line

Food Safety in China: Science, Technology, Management and Regulation, First Edition.
Edited by Joseph J. Jen and Junshi Chen.

of reasoning is also true to a large degree in food-animal production, veterinarians and producers involved in the treatment of disease in food animals bear the additional concern of the persistence of drug residues in the edible tissues after the disease process has been treated [3].

In China, over the last decade, much concern has been focused on the issue of veterinary drug residues in animal-derived food. These concerns are for economic reasons as well as public health. For example, the contamination of milk with antibiotics can affect starter cultures used to make fermented milk products such as cheese, buttermilk, sour cream, and so on. They can result in economic losses to those processors. From the public-health viewpoint, some drugs (such as penicillin) are known to induce allergic reactions in some sensitive people. Similarly, chloramphenicol has been proved to induce bone marrow suppression that may lead to death; hence its use in food-producing animals has been prohibited by the Ministry of Agriculture of China (MOA). The MOA has also prohibited the application of nitrofurans in food-producing animals because these drugs have been shown to be carcinogenic.

14.1.2 Hazards of Drug Residues to Public Health

From the public-health viewpoint, there are direct and indirect hazards relating to veterinary drug residues above the regulatory concentrations. Generally, the former is a short-term hazard, while the latter is a more long term. Some drugs have the potential to produce toxic reactions in consumers directly; for example, approximately 4–11% of the human population is believed to be allergic to penicillin and related drugs [4]. Clenbuterol also caused illness in 70 people as a result of eating contaminated beef in Guangdong in 1990 [5, 6]. Other types of drugs are able to produce allergic or hypersensitivity reactions. For example, β-lactam antibiotics can cause cutaneous eruptions, dermatitis, gastro-intestinal symptoms, and anaphylaxis at very low doses [7]. The aminoglycosides can also cause ototoxicity and nephrotoxicity.

Indirect hazards of drug residues include microbiological effects, carcinogenicity, reproductive effects, and teratogenicity. Microbiological effects are one of the major health hazards in human beings. Antibiotic residues consumed along with edible tissues like milk, meat, and eggs can produce resistance in bacterial populations in consumers [8]. This is one of the major reasons for therapeutic failures amongst such people. Certain drugs like nitroimidazoles can cause cancer in the human population [9]. Similarly, some drugs can produce reproductive and teratogenic effects at very low doses consumed for a prolonged period of time. One such example is vaginal clear cell adenocarcinoma and benign structural abnormalities of the uterus with diethylstilbesterol [10, 11].

14.1.3 Reasons for Drug Residues

Veterinary drugs are administered to animals orally in the feed and water, topically on the skin, by intramuscular and subcutaneous injections, or by intramammary and intrauterine infusions. Theoretically, different routes may lead to varying levels of drug residues. It was shown that injected drugs were responsible for 46% of the violative residues in meat followed by oral administration at 20% (feed, water, and bolus), and intramammary infusions at 7% [12], while in milk, 92% of antibiotic residue was due to the use of intramammary infusions for the treatment of mastitis, followed by injections (6%) and others (2%) [13].

Several other factors also contributed to the residue problem, such as poor treatment records or failure to identify treated animals. Many violations result from the use of a drug in some manner that is inconsistent with the label [14]. This occurs primarily through not observing label withdrawal periods as well as "extra-label" use of the drug. Treatments involving any other method which is not stated on the product label are classified as extra-label usage, and withdrawal times are difficult or impossible to determine in these situations.

14.2 The Regulations Used in China to Prevent and Control Veterinary Drug Residues

14.2.1 Regulation on Administration of Veterinary Drugs

The regulation on administration of veterinary drugs was mainly used to prevent and control veterinary drug residues in China. The first version of this regulation was issued by the State Council on 21 May 1987, and major modifications were made in 2001 and 2004. The current regulation on administration of veterinary drugs in China was adopted at the 45th Executive Meeting of the State Council on 24 March 2004, promulgated by Decree No. 404 of the State Council of the People's Republic of China on 9 April 2004, and effective as of 1 November 2004 [15]. This present regulation consists of nine chapters, including research and development of new veterinary drugs, and the manufacture, distribution, import and export, application, supervision, and administration of veterinary drugs in China [15].

In order to make sure that the regulation on administration of veterinary drugs was smoothly implemented, the MOA developed some appropriate supporting regulations, such as Measures for Registration of Veterinary Drugs [16], Administrative Measures on Prescribed Veterinary Drugs and Over-the-Counter (OTC) Veterinary Drugs [17], and so on.

14.2.2 Veterinary Pharmacopoeia of the People's Republic of China and the Guidelines on the Use of Veterinary Drugs

The Veterinary Pharmacopoeia of the People's Republic of China (abbreviated to the Chinese Veterinary Pharmacopoeia) compiled by the Commission of the Chinese Veterinary Pharmacopoeia was first issued by the MOA in 1990 [18]. As the mandatory state official standard, the Chinese Veterinary Pharmacopoeia is the technical criterion for monitoring and supervising the quality of veterinary medicinal products, as well as the statutory requirements followed in the manufacture, management, examination, and application of veterinary drugs. The National Veterinary Product Inspection Agency investigates and inspects the availability of safe, effective, and good quality essential veterinary medicines according to the official standards enacted in the Chinese Veterinary Pharmacopoeia.

The second, third, and fourth editions of the Chinese Veterinary Pharmacopoeia were brought into effect in 2000 [19], 2005 [20], and 2010 [21], respectively. Now the Veterinary Pharmacopoeia 2015 has been issued, and will be brought into effect on

15 November 2016. This new pharmacopoeia consists of three volumes. Volume I covers monographs on chemical drugs, antibiotics, biochemical preparation, radiopharmaceuticals, and excipients for pharmaceutical use; Volume II deals with monographs of Chinese *materia medica*, including prepared slices of Chinese crude drugs and traditional Chinese formulas; Volume III consists of biological products, antibody products, and diagnostic products. Each volume has its own general notices, appendices, and indexes. There are a total of 1614 monographs and 284 appendixes involved in this new pharmacopoeia.

The Guideline on the Use of Veterinary Drugs for the Chinese Veterinary Pharmacopoeia 2005 was composed in 2005 [22]. Then in 2010, the second Guideline on the Use of Veterinary Drugs was published, in which the maximum residue limits (MRLs) for the marker residues and the withdrawal times for most veterinary drugs were proposed [23].

14.3 The Measures Used in China to Prevent and Control Veterinary Drug Residues

14.3.1 Regulation of Veterinary Drug Application

14.3.1.1 Development of the Standards for Rational Use of Veterinary Drugs

Besides the guidelines on the use of veterinary drugs mentioned above, the MOA also issued standards for the rational use of veterinary drugs in beef cattle [24], dairy cattle [25], pigs [26], sheep [27], broiler chickens [28], hens [29], rabbits [30], and bees [31]. Some of these standards were abolished, but they played a positive role in preventing veterinary drug residues in animal-derived foods.

14.3.1.2 Rational Use of Veterinary Drugs Under the Guidance of Veterinarians

On 1 January 2009, the Measures for the Management of Licensed Veterinarians issued by the MOA came into force [32]. It was stipulated in the measures that China needed to put in place an examination system for practicing veterinary qualifications. On 21 January 2009, the MOA formulated temporary measures for examination of practicing veterinary qualifications, by which the National Examination Commission of Practicing Veterinary Qualifications and the MOA Office for Management of Practicing Veterinaries were set up to strengthen development of the examination system, and carried out trial examinations in two provinces, Henan and Jilin, and two autonomous regions, Guangxi and Ningxia, and the municipality of Chongqing. In 2009, there were 19 895 veterinarians registered for the examination in these five pilot provinces, autonomous regions and the municipality. A total of 5226 examinees passed the examinations and obtained the qualification of licensed veterinarians, of which 1086 were licensed veterinarians and 4140 licensed assistant veterinarians. Then, in 2010, the licensed veterinarian examination of China was held in 167 venues in the 31 provinces, autonomous regions, or municipalities. The licensed veterinarians system was formally established.

In China, a six-level (central, provincial, prefecture, county, township, and village) institutional system has been built up in the animal health sector, supported by a multi-dimensional veterinarian team, composed of official veterinarians, licensed veterinarians, village veterinarians, and village animal disease control workers, who all have the required knowledge, expertise, and professional ethics. Correspondingly, the system improved the competence of animal health workers. Under the guidance of these veterinarians, veterinary drugs are being rationally used in veterinary clinics, which effectively minimizes the risks of misuse of animal veterinary drugs and has lowered veterinary drug residues.

14.3.1.3 Regulations Regarding Prescribed Veterinary Drugs and OTC Veterinary Drugs

The Administrative Measures on Prescribed Veterinary Drugs and OTC Veterinary Drugs was adopted at the 7th Executive Meeting of the MOA on 1 August 2013, promulgated by Decree No. 2 of the MOA of the People's Republic of China on 11 September 2013, and effective as of 1 March 2014. The measures have made explicit stipulations on cautionary areas during the management, production, sales, purchase, and use of prescribed and non-prescribed veterinary drugs [17]. According to the measures, the MOA illuminated how to regulate the use of veterinary drug product labels and instructions on 18 February 2014 [33], and issued the directory of basic veterinary drugs used by village veterinarians on 28 February 2014 [34]. The system of prescribed veterinary drugs effectively reduces the risk of veterinary drug residues.

14.3.2 Implementing the Monitoring and Control Plan for Veterinary Drug Residues

In March 1999, the MOA laid down the Plan of the People's Republic of China for the Control of Veterinary Drug Residues in Animals and Food of Animal Origin, and at the same time issued the official sampling procedures and formulated the 1999 Implementation Scheme for Residue Control and Sampling [35]. The monitoring and control plan includes seven aspects: (a) the laws and regulations related to the monitoring and control of veterinary drug residues; (b) the organization structures of departments in the monitoring and control system; (c) the laboratory detection network and its capability; (d) control measures for business and government; (e) official sampling details; (f) material testing and analytical methods; and (g) penalties for excess veterinary drug residues [35].

Since 1999, the MOA has developed the monitoring and control plan for veterinary drug residues every year. The average annual batch of tested samples stands at 14 000. Up to 24 veterinary drugs (including ceftiofur, thiamphenicol, macrolides, and so on.) were monitored for residues in a total of nine kinds of animal-derived foods, including meat, eggs, and milk. The failure rate in 2015 was 0.11% (down from 1.43% in 1999). In 2015 [36], 12 165 batches of samples from chicken, cattle, sheep/goats, and pigs were tested, and 23 drugs were covered. The monitoring and control plans from 1999 to 2007 can be found in Table 14.1 [37].

The latest results of monitoring and control showed that in 2015 a total of 13 201 batches of livestock and poultry products (listed in Table 14.2) were detected for 22 drug residues, and the pass rate was 99.92% [38, 39]. Among the total of 13 201 batches of livestock and poultry products, only 11 batches did not pass. Besides the livestock and poultry products, a total of 370 batches of bee products were tested in 2015, with a pass rate of 92.7% [39].

Table 14.1 The statistics on the monitoring and control plans on veterinary drug residues from 1999 to 2007.

Year	Planned batches	Kinds of tissues to be monitored	Kinds of drugs to be monitored	Number of places to be monitored
1999	1620	4	11	10
2000	4660	8	12	20
2001	4460	12	13	27
2002	19810	12	17	26
2003	17116	11	12	30
2004	13810	25	13	30
2005	14590	27	21	30
2006	15801	28	18	30
2007	16358	33	21	30

Source: Data derived from Dong and Yuan (2008) [37].

14.3.3 Determination and Amendment of the Maximum Residue Limits for Veterinary Drugs Used in Food Animals

The MOA has been intensifying work on MRLs for veterinary drugs; the classification of standards is more scientific, with a substantial increase of the number of formulations. Since 1997, the MOA has released MRLs for veterinary drugs in food of animal origin four times. The first were issued on 4 February 1994, and comprised 42 veterinary drugs. After three years of trials, the MOA revised the previously published MRLs on 1 September 1997, and added MRLs for five new veterinary drugs. On 13 September 1999, the MOA substantially modified the previous MRLs. This new collection clearly labeled the target tissues in different animal species and the marker residues for 109 veterinary drugs. On 24 December 2002, the MOA released the latest standards for MRLs for veterinary drugs used in food animals [40]. This standard consists of four appendices: Appendix 1 contains 88 veterinary drugs that are allowed to be used in food animals and for which there is no need to determine MRLs; Appendix 2 contains 94 veterinary drugs and their MRLs; Appendix 3 contains 9 veterinary drugs that are allowed to be therapeutically used in food animals, but the residues cannot be detected in animal-derived food; Appendix 4 contains 31 veterinary drugs that are prohibited from being used in food animals.

Internationally, the MRLs are mainly based on the standards issued by the Codex Alimentarius Commission (CAC), a body that was established in early November 1961 jointly by the Food and Agriculture Organization of the United Nations (FAO), and the World Health Organization (WHO), and held its first session in Rome in October 1963. Most MRLs for drugs used in China are also based on the CAC standards, and a few others are derived from the standards of the United States or the European Union. It is known that 302 MRLs used in China are identical to those used by the CAC, 26 MRLs are lower than those adopted by the CAC, and only 8 MRLs are higher than those used by CAC. In other words, 98% of MRLs adopted in China reach or surpass the CAC standards.

Table 14.2 Tests for veterinary drug residues in animal products in 2015.[a]

Animals	Tissues for testing	Drugs for residue testing
Chicken	Eggs	Fluoroquinolones, nitrofuran metabolites (AOZ, AMOZ, AHD, and SEM)
	Liver	Sulfonamides, chloramphenicol, dimetridazole/metronidazole
	Meat	Diclazuril, fluoroquinolones, sulfanilamides, chloramphenicol, clopidol, marker residues of nicarbazin, tetracyclines, tylosin, tilmicosin, nitrofuran metabolites (AOZ, AMOZ, AHD, and SEM)
Cattle	Milk	β-Lactams, avermectins, dexamethasone, fluoroquinolones, sulfanilamides, thiamphenicol, lincosamides and macrolides
	Beef	Avermectins, clenbuterol, anabolic sex hormones, ceftiofur
Sheep/goat	Mutton	Clenbuterol, sulfanilamides
Pig	Liver	β-Agonist, marker residues of carbadox and olaquindox
	Urine	β-Agonist
	Pork	Dimetridazole/metronidazole, dexamethasone, fluoroquinolones, sulfanilamides, tetracycline, tilmicosin, ceftiofur, nitrofuran metabolites (AOZ, AMOZ, AHD, and SEM)
Bee	Honey	Chloramphenicol, nitroimidazoles (metronidazole, ronidazole, dimetridazole), nitrofuran metabolites (AOZ, AMOZ, AHD, and SEM), fluoroquinolones, sulfonamides, tetracyclines
Aquatic animals, such as fish, crawfish, prawn, Chinese soft shell turtle, etc.	Muscle	Chloramphenicol, Malachite Green, nitrofuran metabolites (AOZ, AMOZ, AHD, and SEM), olaquindox, diethylstilbestrol (DES), methyltestosteron

a) These data were deverived from the circular on the plan of the People's Republic of China for the control of veterinary drug residues in animals and food of animal origin in 2015, which is available from http://www.moa.gov.cn/govpublic/SYJ/201502/t20150212_4408142.htm.

14.3.4 Establishment of the National Expert Committee on Veterinary Drug Residues

The first National Expert Committee on Veterinary Drug Residues was established in 1999 [41]. It provides technical consultations regarding monitoring of veterinary drug residues in animals and animal products. Its major responsibilities include drafting, reviewing, and revising the national monitoring plans, and evaluating their effects; commenting the plan for developing and revising national standards for veterinary drug residues, and carrying out major research programs on such standards; reviewing the draft and revision of the national standards, and relevant technical codes for residue monitoring; participating in technical exchange activities with relevant international organizations; and performing the duties related to the Subcommittee on Veterinary Drug Residues of the National Food Safety Standards Review Committee [42]. The second [43] and third committees [44] on veterinary drug residues were established in 2005 and 2013, respectively.

14.3.5 Establishment of Standards for the Detection of Veterinary Drug Residues in Animal-Derived Food

In order to monitor and control veterinary drug residues and further avoid their risks, the MOA established standard methods for veterinary drug residues as early as the 1980s. In 2008, the Veterinary Bureau of the MOA published a collection of standards for testing methods for veterinary drug residues in food of animal origin, and amended another 39 standards for testing methods for veterinary drug residues. On 16 September 2013, the MOA published another 29 standards, including Determination of Levamisole Residues in Milk – HPLC Method. A database of information on residue testing standards was successfully built by the MOA. At present, there are 48 standard methods used to determine drug residues. The MOA also reviewed and filed information on rapid residue testing kits, introduced provisions on the withdrawal periods for 202 common veterinary drugs and feed additives, and promulgated rules on the use of medicinal feed additives. At present, the MOA provides special funds each year to develop and revise the standard methods for detecting the veterinary drug residues.

14.3.6 Databank of the Application of Domestic and Foreign Veterinary Drugs and Drug Residues in Animal-Derived Food

The databank of the application of domestic and foreign veterinary drugs and drug residues in animal-derived food was supported by the Ministry of Commerce of the People's Republic of China and launched on 31 March 2006. This databank [45] collected the veterinary drugs used in the USA, the EU, Australia, and China, and the MRLs for these drugs. It also contained the active ingredients, dosage form, method of administration, indications, usage, dosage, and withdrawal period of these veterinary drugs. The main purpose of this databank is to guide the rational use of these drugs and to avoid their residues in food. It is free of charge for any unit or individual.

14.3.7 Strengthening the Construction of Veterinary Drug Residues Detection Laboratories

Since 1998, the MOA has established four national reference laboratories for the testing of veterinary drug residues and more than 20 provincial veterinary drug residue detection laboratories. The laboratory transformations and the updating of equipment and facilities were completed in 2014. In order to enhance the capacity for monitoring and controlling veterinary drug residues, since 2010 the MOA has organized proficiency testing (PT) of the laboratories every year. All national reference laboratories and provincial veterinary drug residue detection laboratories participate in the test.

14.4 Measures and Policies that Should be Applied in Future to Monitor and Control Veterinary Drug Residues in China

14.4.1 Perfection of Animal-Derived Food Safety Regulation System

14.4.1.1 Improving the Veterinary Drug Residue Database

To improve the current veterinary drug residue database, more basic information, such as physical and chemical properties of the approved veterinary drugs, data on their pharmacodynamics, pharmacokinetics, adverse drug reaction, medical indications, toxicity to consumers' health, and animal-derived food consumption data, should be provided [46]. In addition, sub-databases can be established based on the experience of developed countries: [47]

1) *Analytical method database.* This database presents a critical inventory of methods available for the analysis of residues for growth promoters and veterinary drugs, which are or will be regulated by Chinese regulations directives and decisions. Published papers are systematically searched to collect analytical methods for rapid screening and confirmation of residues in animal food products. Then these methods are strictly validated with respect to specificity, linearity, limits of detection and quantity, accuracy, precision, and robustness according to certain criteria. Thereafter, the validated methods are classified as "high reliability" or "limited reliability" according to their conformity with the criteria. High reliability, meaning that the validation results completely meet the criteria, is defined as A and limited reliability, meaning that the validation results partly meet the criteria, is defined as B.

   The analytical method database contains the following information: references (authors, journal, years of publication, and correspondence address of the first author); the scope of application of the method (urine, kidney, muscle, etc.); the residues that can be screened or confirmed; sample preparation and analysis; features of the method; limits of detection and quantification; classification: A or B.
2) *Legislation and monitoring program databases.* The legislation database presents an inventory of the legislation in China with regard to drug residues in animal products, and the monitoring program database presents qualitative and quantitative data about the MOA monitoring programs.

14.4.1.2 Application of Hazard Analysis and Critical Control Points (HACCP) System in Animal Husbandry

In order to control veterinary drug residues from farm to fork, animal-derived food should be produced according to good agricultural practice (GAP), good veterinary practice (GVP), good manufacturing practice (GMP), and good hygiene practice (GHP) or sanitation standard operating procedure (SSOP). In addition, Hazard Analysis and Critical Control Points (HACCP), a systematic approach for identification and control of hazards associated with food production [48] needs to be implemented to ensure food safety [49].

14.4.1.3 Promoting a Market Access System, and a Tracking and Traceability System for Animal-Derived Food

To keep non-conforming products away from market, thus ensuring consumption without concern about food safety and to protect the health of consumers, measures should be taken to gradually popularize a market access system across China by supervision of food producing process and inspection of the final products. Additionally, the execution of a tracking and traceability system needs to be improved to track the non-compliant samples, so that traceability of animal-derived food can be realized. Furthermore, it is imperative to institute a commitment system for assurance of quality and safety of animal-derived food.

14.4.1.4 Strengthening Residue Supervision and Regulation Enforcement

On the basis of the current veterinary drug residue monitoring program, it is necessary to further increase the number, coverage, and frequency of sampling in the future. To prevent illegal activities such as illegal use of banned chemicals in food-producing animals, it is essential to strengthen inspection of products and increase the severity of punishment.

14.4.2 Strengthening the Construction of the Veterinary Drug Administration System

14.4.2.1 Strengthening the Legal Framework of Veterinary Drug Administration

To provide a strong legal guarantee for veterinary drug residue monitoring and food security assurance, it will be necessary to turn the current “veterinary drug regulation” into “veterinary drug law” by summing up the experiences and issues in veterinary drug administration [37].

14.4.2.2 Implementing a Certified Veterinarian and Veterinary Officer System

It is necessary to construct a certified veterinarian system in China because certified veterinarians play an important role in a veterinary team. Although examination of their qualifications has been carried out, effective measures still need to be taken to strengthen the construction of the system and define certified veterinarians’ rights and obligations on medication, and prevention and control of animal diseases, so that they can actually play a key role in husbandry development and food safety assurance [50].

It is also essential to set up an official veterinary system through legislation with international standards. In this system, official veterinarians are vertically administered by an administrative department of veterinary, and they are responsible for effective supervision of animal disease prevention and control, and of animal and animal products throughout all stages of the production process, thus fairness, scientific facts, and systematic regulation enforcement in veterinary health can be achieved [49].

14.4.3 Strengthening Construction of Veterinary Drug Residue Standards

14.4.3.1 Strengthening the Construction of Standards for Veterinary Drug Residue Limits

In comparison with the standards in developed countries, Chinese veterinary drug residue limits are updated slowly. A large proportion of the current standards in this field set by the EU, the US, Japan, and the CAC are stricter than those in China. Therefore, we have to speed up setting relevant standards for those drugs which have not been included in the current standards, especially for antibiotics and hormones. Based on the use of veterinary drugs in animal husbandry in China, scientific and reasonable residue limits can be formulated [51]. Meanwhile, we should establish a risk assessment system for veterinary drug residues and conduct research on standards of veterinary drug residue limits based on our eating habits, and the situation in China [49].

14.4.3.2 Establishing Withdrawal Periods

Withdrawal is a treatment-free period before an animal, or animal food products, can be used for human consumption. This time allows the drug and its residues to decrease to concentrations that do not pose any demonstrable health risk to consumers [52]. As it varies by animal, drug, formulation, dosage and route of administration, and drug distribution in tissue, we need to establish a specific withdrawal period for each newly approved veterinary drug and its formulations.

14.4.3.3 Standards for Veterinary Drug Residue Analysis

The level of food safety depends on the analytical technology. Up to now, more than 500 standards for veterinary drug residue analysis in the most important food products have been established in China, ensuring safety of animal-dervived food in our country. However, lower veterinary drug residue limits set by many developed countries using advanced analytical technology have the potential to pose barriers to trade. So we need to improve equipment and analytical method standards to make sure that animal-derived food can be exported without obstacles. Standard methods for fast screening are in especially urgent need.

14.4.4 Strengthening Scientific and Technological Support for Veterinary Drug Residues

14.4.4.1 Strengthening Fundamental Research on Veterinary Drug Residues and Food Safety

To provide a scientific basis for veterinary drug residue analysis, fundamental research that is related to the mechanism by which residues are generated, metabolism and elimination *in vivo*, and harm to target animals and consumers is needed [49].

14.4.4.2 Developing and Improving Analytical Methods for Screening and Confirmation

Analytical Methods for Fast Screening

Fast screening involves a great number of samples. Compliant samples are accepted while the suspected non-compliant samples have to be further analyzed using confirmatory methods [3]. Therefore, screening methods that are cheaper, easier to use and handle, suitable for multi-residue analysis and field screening, and have greater sensitivity, higher throughput, and wider detection range are required. Besides the classical methods, such as immunological techniques (e.g., enzyme-linked immunosorbent assay (ELISA) and colloidal gold immunochromatographic assay (GICA)), high performance thin-layer chromatography (HPTLC) and high performance liquid chromatography (HPLC), efforts can be made to realize the potential of other methods, such as biosensor techniques [53–55] that utilize the optical phenomenon of surface plasma resonance (SPR) to monitor biological interaction [56], and suspension array technology, which is a transfer of the microarray format from a glass slide (planar and solid microarray) to an efficient and high-throughput microsphere format [57–59].

Confirmatory Analytical Methodologies

After initial screening, suspected non-compliment samples need to be confirmed. The analysis of residues in animal-derived food has undergone a tremendous evolution during the past decades [60]. Liquid chromatography-mass spectrometry (LC-MS), gas chromatography-mass spectrometry (GC-MS), and capillary electrophoresis-mass spectrometry (CE-MS) are often used as confirmatory analytical methodologies currently. In the future, it can be foreseen that using more and more sophisticated and expensive machines like high resolution mass spectrometers will be the direction of development [61, 62]. LC-MS/MS methods for multi-class, multi-residue analysis of veterinary drugs and their metabolites have also been developed in recent years [63–65].

The analysis results are strongly correlated with the efficacy of the sample clean-up [60], which are generally expensive, laborious, and time-consuming in confirmatory analysis. The most popular sample preparation methodology is still the combined use of liquid-liquid extraction (LLE) and on-line or off-line solid phase extraction (SPE). Simplified sample preparation procedures that are generic for multi-class compounds, cost- and time-effective, amenable to automation and high-throughput, and require less solvent, such as QuEChERS methodology (Quick, Easy, Cheap, Effective, Rugged, and Safe) that mainly consists of a simple liquid extraction step with filtration and no further sample clean-up [53, 66, 67], novel solid-phase microextraction (SPME) [68], pressurized liquid extraction (PLE), matrix solid phase dispersion (MSPD), restricted access materials (RAMs), molecularly imprinted polymers (MIPs), and turbulent flow chromatography (TFC) are expected to be developed for residue analysis in animal-derived food. Novel strategies in this field have been reviewed by Marazuela *et al.* [69] and Kinsella *et al.* [70].

Combination of Screening and Confirmatory Testing

Further trends in analytical methods will be focused towards combination of screening and confirmatory testing. On-line turbulent flow chromatography–liquid chromatography–tandem mass spectrometry is a combined approach for screening and confirmation [71–73]. Although the instrument is costly, it is a competitive alternative because of its high efficiency when a large number of samples are to be handled and analyzed [74].

14.4.4.3 Strengthening the Development and Promotion of the Use of Natural Animal Medicines and their Formulations

Since the heavy use of antibiotics in animal production causes concern about risks of harm to human health and the environment, development and use of substitute products such as herbal medicines, fermented feed, microbiological additives, and enzyme additives are encouraged.

14.4.4.4 Strengthening International Cooperation and Communication

To gradually enhance the role and influence of China in international standard-setting, and to improve management level and residue detection ability by studying other countries' experiences, it is necessary to continue attending the Codex Committee on

Residues of Veterinary Drugs in Foods (CCRVDF) meetings, and other international meetings on veterinary drug safety evaluation [37, 49].

14.4.4.5 Strengthening Talent Cultivation and Training

There is still room to support the cultivation of talented professionals who are engaged in administration, analysis, and research work on veterinary drug residues and food safety. Meanwhile, more measures need to be taken to train farmers on scientific breeding, animal disease prevention and control, and to guide them to use veterinary drugs rationally, so that the origin of the residue problem can be controlled [37, 48].

14.4.5 Strengthening Publicity, Education and Mass Supervision

First, we have to improve farmers' legal education and convince them that safe food production is their obligation. We should also offer technical training and improve their knowledge on rational use of veterinary drugs. Second, we should take some measures to improve the awareness of administrators that they can enforce regulations seriously and fairly. Third, we should promote marketing, improve consumers' awareness of protecting their rights, and encourage mass supervision [49].

References

1. Bartikova, H., Podlipna, R., Skalova, L. (2016) Veterinary drugs in the environment and their toxicity to plants. *Chemosphere*, 144, 2290–2301.
2. Baynes, R.E., Dedonder, K., Kissell, L., *et al.* (2016) Health concerns and management of select veterinary drug residues. *Food and Chemical Toxicology*, 88, 112–122.
3. Reig, M., Toldrá, F. (2008) Veterinary drug residues in meat: concerns and rapid methods for detection. *Meat Science*, 78(1–2), 60–67.
4. Dayan, A.D. (1993) Allergy to antimicrobial residues in food: assessment of the risk to man. *Veterinary Microbiology*, 35(3–4), 213–226.
5. Dong, F., Gong, C., Wang, Z., Qi, C. (2013) Investigation on pollution status of meat and meat products sold in Yantai City in 2011. *Occupation and Health*, 29(9), 1096–1097 [in Chinese].
6. Song, X., Zhang, L., Jiang, J. (2014) Monitoring results of contaminants in some market food of Dalian City in 2013. *Occupation and Health*, 30(22), 3225–3231 [in Chinese].
7. Paige, J.C., Tollefson, L., Miller, M. (1997) Public health impact on drug residues in animal tissues. *Veterinary and Human Toxicology*, 39(3), 162–169.
8. Yang, F., Liu, H.W., Li, M., *et al.* (2012) Use of a Monte Carlo analysis within a physiologically based pharmacokinetic model to predict doxycycline residue withdrawal time in edible tissues in swine. *Food Additives and Contaminants Part A: Chemistry Analysis Control Exposure & Risk Assessment*, 29(1), 73–84.
9. Lv, P.C., Zhu, H.L. (2015) Nitroimidazole derivatives: a patent review of US 2014/0141084 A1. *Expert Opinion on Therapeutic Patents*, 25(4), 489–492.
10. Sharp, G.B., Cole, P. (1991) Identification of risk factors for diethylstilbestrol-associated clear cell adenocarcinoma of the vagina: similarities to endometrial cancer. *American Journal of Epidemiology*, 134(11), 1316–1324.

11 Palmer, J.R., Anderson, D., Helmrich, S.P., Herbst, A.L. (2000) Risk factors for diethylstilbestrol-associated clear cell adenocarcinoma. *Obstetrics and Gynecology*, 95(6 Pt 1), 814–820.

12 Mitchell, J.M., Griffiths, M.W., Mcewen, S.A., *et al.* (1998) Antimicrobial drug residues in milk and meat: causes, concerns, prevalence, regulations, tests, and test performance. *Journal of Food Protection*, 61(6), 742–756.

13 Mcewen, S.A., Black, W.D., Meek, A.H. (1992) Antibiotic residues (bacterial inhibitory substances) in the milk of cows treated under label and extra-label conditions. *Canadian Veterinary Journal*, 33(8), 527–534.

14 Sundlof, S.F. (1989) Drug and chemical residues in livestock. *Veterinary Clinics of North America: Food Animal Practice*, 5(2), 411–449.

15 MOA (2004) *Regulation on Administration of Veterinary Drugs*, http://www.gov.cn/gongbao/content/2004/content_62760.htm (accessed February 2016) [in Chinese].

16 MOA (2012) *Measures for Registration of Veterinary Drugs*, http://www.moa.gov.cn/fwllm/zxbs/xzxk/bszl/syj/201204/t20120426_2612402.htm (accessed February 2016) [in Chinese].

17 MOA (2013) *Administrative Measures on Prescribed Veterinary Drugs and OTC Veterinary Drugs*, http://www.gov.cn/gongbao/content/2013/content_2528114.htm (accessed February 2016) [in Chinese].

18 Commission of Chinese Veterinary Pharmacopoeia (1990) *Veterinary Pharmacopoeia of the People's Republic of China*, China Agriculture Press, Beijing [in Chinese].

19 Commission of Chinese Veterinary Pharmacopoeia (2000) *Veterinary Pharmacopoeia of the People's Republic of China*, China Agriculture Press, Beijing [in Chinese].

20 Commission of Chinese Veterinary Pharmacopoeia (2005) *Veterinary Pharmacopoeia of the People's Republic of China*, China Agriculture Press, Beijing [in Chinese].

21 Commission of Chinese Veterinary Pharmacopoeia (2010) *Veterinary Pharmacopoeia of the People's Republic of China*, China Agriculture Press, Beijing [in Chinese].

22 Commission of Chinese Veterinary Pharmacopoeia (2005) *Guidelines on the Use of Veterinary Drugs 2005*, China Agriculture Press, Beijing [in Chinese].

23 Commission of Chinese Veterinary Pharmacopoeia (2010) *Guidelines on the Use of Veterinary Drugs 2010*, China Agriculture Press, Beijing [in Chinese].

24 NY 5125-2002. (2002) *Guidelines on the Use of Veterinary Drugs for Pollution-Free Food in Beef Cattle*, MOA, Beijing [in Chinese].

25 NY 5046-2001. (2001) *Guidelines on the Use of Veterinary Drugs for Pollution-Free Food in Dairy Cattle*, MOA, Beijing [in Chinese].

26 NY 5030-2001. (2001) *Guidelines on the Use of Veterinary Drugs for Pollution-Free Food in Pigs*, MOA, Beijing [in Chinese].

27 NY 5148-2002. (2002) *Guidelines on the Use of Veterinary Drugs for Pollution-Free Food in Sheep or Goats*, MOA, Beijing [in Chinese].

28 NY 5035-2001. (2001) *Guidelines on the Use of Veterinary Drugs for Pollution-Free Food in Broiler Chickens*, MOA, Beijing [in Chinese].

29 NY 5040-2001. (2001) *Guidelines on the Use of Veterinary Drugs for Pollution-Free Food in Laying Hens*, MOA, Beijing [in Chinese].

30 NY 5130-2002. (2002) *Guidelines on the Use of Veterinary Drugs for Pollution-Free Food in Rabbits*, MOA, Beijing [in Chinese].

31 NY 5138-2002. (2002) *Guidelines on the Use of Veterinary Drugs for Pollution-Free Food in Honeybees*, MOA, Beijing [in Chinese].

32 MOA (2008) *Measures for Management of Licensed Veterinarians*, http://www.gov.cn/gzdt/2008-12/09/content_1172844.htm (accessed February 2016) [in Chinese].

33 MOA (2014) *Announcement No. 2066 of the Ministry of Agriculture*, http://www.moa.gov.cn/zwllm/tzgg/gg/201402/t20140220_3790892.htm (accessed February 2016) [in Chinese].

34 MOA (2014) *Announcement No. 2069 of the Ministry of Agriculture*, http://www.moa.gov.cn/govpublic/SYJ/201403/t20140303_3801667.htm?keywords= (accessed February 2016) [in Chinese].

35 MOA (1999) *Plan of the People's Republic of China for the Control of Veterinary Drug Residues in Animals and Food of Animal Origin and Official Sampling Procedure*, http://www.moa.gov.cn/govpublic/XMYS/201006/t20100606_1534901.htm (accessed February 2016) [in Chinese].

36 MOA (2015) *Circular on the Plan of the People's Republic of China for the Control of Veterinary Drug Residues in Animals and Food of Animal Origin in 2015*, http://www.moa.gov.cn/govpublic/SYJ/201502/t20150212_4408142.htm (accessed February 2016) [in Chinese].

37 Dong, Y., Yuan, Z. (2008) Current Trends and Suggestions for veterinary drug residue in China. *Chinese Journal of Animal Quarantine*, 25 (11), 19–21 [in Chinese].

38 MOA (2016) *Notification on the Results of the Monitoring and Control Plans for Veterinary Drug Residues in the First Half of 2005 Issued by the General Office of the MOA*, http://www.moa.gov.cn/govpublic/SYJ/201508/t20150828_4808876.htm (accessed February 2016) [in Chinese].

39 MOA (2016) *Notification on the Results of the Monitoring and Control Plans On Veterinary Drug Residues in the Second Half of 2005 Issued by the General Office of the MOA*, http://www.moa.gov.cn/govpublic/SYJ/201602/t20160218_5021442.htm (accessed February 2016) [in Chinese].

40 MOA (2002) *Announcement No. 235 of the Ministry of Agriculture*, http://www.moa.gov.cn/zwllm/nybz/200803/t20080304_1028649.htm (accessed February 2016) [in Chinese].

41 MOA (1999) *Circular on Setting Up the National Expert Consulting Group on Veterinary Drug Residues*, http://www.moa.gov.cn/ztzl/xumugb/2000-2-4.htm#01 (accessed February 2016) [in Chinese].

42 MOA (1999) *Administraion Measurements of the National Expert Consulting Group of Veterinary Drug Residues*, http://www.moa.gov.cn/ztzl/xumugb/2000-2-4.htm#01 (accessed February 2016) (in Chinese).

43 MOA (2005) *Notification on the Establishment of the Second National Expert Committee on Veterinary Drug Residues*, http://www.moa.gov.cn/govpublic/SYJ/201006/t20100606_1535521.htm (accessed February 2016) [in Chinese].

44 MOA (2013) *Notification on the Establishment of the Third National Expert Committee on Veterinary Drug Residues*, http://www.moa.gov.cn/govpublic/SYJ/201302/t20130226_3227159.htm (accessed February 2016) [in Chinese].

45 Ministry of Commerce of the People's Republic of China (2006) *The Databank of the Application of Domestic and Foreign Veterinary Drugs and Drug of the Application of Domestic and Foreign Veterinary Drugs and Residues in Animal-Derived Food*, http://sysy.sms.mofcom.gov.cn/index.jsp (accessed February 2016) [in Chinese].

46 Shen, F., Gu, X., Pang, Y. (2005) Introduce for veterinary drug residue database of the European Union. *Chinese Journal of Veterinary Drug*, (12), 36–38 [in Chinese].

47 Van Peteghem, C., Maghuin-Rogister, G. *Standardization of Hormone and Veterinary Drug Residue Analysis in Animal Products*, http://cemu10.fmv.ulg.ac.be/OSTC/ (accessed February 2016)

48 Hulebak, K.L., Schlosser, W. (2002) Hazard analysis and critical control point (HACCP) history and conceptual overview. *Risk Analysis*, 22(3), 547–552.

49 Chen, Z., Zeng, Z. (2003) Thinking about the veterinary drugs residues in animal-derived food in China. *China Animal Health*, 5(12), 6–10 [in Chinese].

50 Wu, H., Weng, C. (2009) Certified Veterinarian and Certified Veterinarian System. *Chinese Journal of Veterinary Drug*, 55(10), 29–33 [in Chinese].

51 Tian, H., Li, J., Zhou, T., *et al.* (2012) Comparative analysis of standards for veterinary drug residue limits among China, the EU, Japan, the US and the Codex Alimentarius Commission (CAC). *Meat Research*, 26(2), 43–46 [in Chinese].

52 Health Canada (2013) *The Veterinary Drug Approval Process*, http://www.hc-sc.gc.ca/dhp-mps/vet/faq/faq_dap-pam-eng.php (accessed February 2016).

53 Keegan, J., Whelan, M., Danaher, M., *et al.* (2009) Benzimidazole carbamate residues in milk: Detection by Surface Plasmon Resonance-biosensor, using a modified QuEChERS (Quick, Easy, Cheap, Effective, Rugged and Safe) method for extraction. *Analytica Chimica Acta*, 654(2), 111–119.

54 Haughey, S.A., Baxter, G.A. (2006) Biosensor screening for veterinary drug residues in foodstuffs. *Journal of AOAC International*, 89(3), 862–867.

55 Keegan, J., O'Kennedy, R., Crooks, S., *et al.* (2011) Detection of benzimidazole carbamates and amino metabolites in liver by surface plasmon resonance-biosensor. *Analytica Chimica Acta*, 700(1–2), 41–48.

56 Baxter, G.A., Ferguson, J.P., O'Connor, M.C., Elliott, C.T. (2001) Detection of streptomycin residues in whole milk using an optical immunobiosensor. *Journal of Agricultural and Food Chemistry*, 49(7), 3204–3207.

57 Liu, N., Su, P., Gao, Z., *et al.* (2009) Simultaneous detection for three kinds of veterinary drugs: chloramphenicol, clenbuterol and 17-beta-estradiol by high-throughput suspension array technology. *Analytica Chimica Acta*, 632(1), 128–134.

58 Liu, N., Gao, Z., Ma, H., *et al.* (2013) Simultaneous and rapid detection of multiple pesticide and veterinary drug residues by suspension array technology. *Biosensors and Bioelectronics*, 41(1), 710–716.

59 Su, P., Liu, N., Zhu, M., *et al.* (2011) Simultaneous detection of five antibiotics in milk by high-throughput suspension array technology. *Talanta*, 85(2), 1160–1165.

60 Croubels, S. and Daeseleire, E. (2012) *Veterinary drug residues in foods, in Veterinary Drug Residues in Foods: Chemical Contaminants and Residues in Food* (ed. D. Schrenk), Woodhead Publishing Limited, Sawston, pp. 148–182.

61 Wang, X., Liu, Y., Su, Y., *et al.* (2014) High-throughput screening and confirmation of 22 banned veterinary drugs in feedstuffs using LC-MS/MS and high-resolution Orbitrap mass spectrometry. *Journal of Agricultural and Food Chemistry*, 62(2), 516–527.

62 Kaufmann, A., Butcher, P., Maden, K., *et al.* (2011) Development of an improved high resolution mass spectrometry based multi-residue method for veterinary drugs in various food matrices. *Analytica Chimica Acta*, 700(1–2), 86–94.

63 Sapozhnikova, Y., Lehotay, S.J. (2013) Multi-class, multi-residue analysis of pesticides, polychlorinated biphenyls, polycyclic aromatic hydrocarbons, polybrominated diphenyl ethers and novel flame retardants in fish using fast, low-pressure gas chromatography-tandem mass spectrometry. *Analytica Chimica Acta*, 758(3), 80–92.

64 Schneider, M.J., Lehotay, S.J., Lightfield, A.R. (2012) Evaluation of a multi-class, multi-residue liquid chromatography-tandem mass spectrometry method for analysis of 120 veterinary drugs in bovine kidney. *Drug Testing and Analysis*, 4 (Suppl 1), 91–102.

65 Zhang, Y., Li, X., Liu, X., *et al.* (2015) Multi-class, multi-residue analysis of trace veterinary drugs in milk by rapid screening and quantification using ultra-performance liquid chromatography-quadrupole time-of-flight mass spectrometry. *Journal of Dairy Science*, 98(12), 8433–8444.

66 Zhang, D., Park, J.A., Kim, S.K., *et al.* (2015) Determination of residual levels of naloxone, yohimbine, thiophanate, and altrenogest in porcine muscle using QuEChERS with liquid chromatography and triple quadrupole mass spectrometry. *Journal of Separation Science*, 39(5), 835–841.

67 Shendy, A.H., Al-Ghobashy, M.A., Gad, A.S., Lotfy, H.M. (2016) Development and validation of a modified QuEChERS protocol coupled to LC-MS/MS for simultaneous determination of multi-class antibiotic residues in honey. *Food Chemistry*, 190, 982–989.

68 Kataoka, H., Saito, K. (2011) Recent advances in SPME techniques in biomedical analysis. *Journal of Pharmaceutical and Biomedical Analysis*, 54(5), 926–950.

69 Marazuela, M.D., Bogialli, S. (2009) A review of novel strategies of sample preparation for the determination of antibacterial residues in foodstuffs using liquid chromatography-based analytical methods. *Analytica Chimica Acta*, 645(1–2), 5–17.

70 Kinsella, B., O Mahony, J., Malone, E., *et al.* (2009) Current trends in sample preparation for growth promoter and veterinary drug residue analysis. *Journal of Chromatography A*, 1216(46), 7977–8015.

71 Zhu, W.X., Yang, J.Z., Wang, Z.X., *et al.* (2016) Rapid determination of 88 veterinary drug residues in milk using automated TurborFlow online clean-up mode coupled to liquid chromatography-tandem mass spectrometry. *Talanta*, 148, 401–411.

72 Aguilera-Luiz, M.M., Romero-Gonzalez, R., Plaza-Bolanos, P., *et al.* (2013) Rapid and semiautomated method for the analysis of veterinary drug residues in honey based on turbulent-flow liquid chromatography coupled to ultrahigh-performance liquid chromatography-Orbitrap mass spectrometry (TFC-UHPLC-Orbitrap-MS). *Journal of Agricultural and Food Chemistry*, 61(4), 829–839.

73 Stolker, A.A., Peters, R.J., Zuiderent, R., *et al.* (2010) Fully automated screening of veterinary drugs in milk by turbulent flow chromatography and tandem mass spectrometry. *Analytical and Bioanalytical Chemistry*, 397(7), 2841–2849.

74 Huang, X., Shen, D. (2014) The application status and progress in detection of veterinary drug residues. *Chinese Journal of Veterinary Drug*, 48(7), 66–69 [in Chinese].

15

Heavy Metal Contamination

Dajin Yang[1]*, Kai Zhao*[2]*, Fabrizis Suarez*[3]*, Lawrence Pacquette*[3] *and Daniel Schmitz*[3]

[1] *China National Center for Food Safety Risk Assessment, Beijing, China*
[2] *Chemical Foreign Economic Cooperation Center, Beijing, China*
[3] *Abbott Nutrition, USA*

A heavy metal is defined as an element with a relative density of more than 5 g/cm^3, however other schemes have been utilized to describe what actually constitutes a heavy metal [1]. In addition to density, schemes include categorization by atomic weight, toxicity, chemical form, and metallic properties [2–7]. For the purposes of this book, heavy metals will be defined as those elements with metallic properties (metals or semimetals) that have the potential to cause adverse health effects in humans/animals or be toxic to the environment [8]. From a food contamination perspective, the most common heavy metals include lead (Pb), cadmium (Cd), mercury (Hg), and arsenic (As). Chromium (Cr), nickel (Ni), tin (Sn), aluminum (Al), barium (Ba), and lithium (Li) are also considered as common heavy metals that contaminate foods. Other metal elements are considered to be essential micronutrients (e.g., copper [Cu], zinc [Zn], and iron [Fe]) that maintain various biochemical and physiological functions in humans when present in very low levels, but cause potentially toxic effects when they exceed certain threshold concentrations [9].

Heavy metals are present in most agro ecosystems and come from two sources: inherited parent materials (e.g., those metals occurring naturally in the soil) or input from human activities [10]. Trace levels of heavy metals occur naturally in the environment and are widely distributed in the earth's material [9–12]. However, the extensive use of these metals in mining and smelting operations, industrial manufacturing, and domestic and agricultural applications due to rapid industrialization and urbanization is having profound effects on food safety and has caused widespread heavy metal contamination of the ground soil, water, and air [3, 10, 13]. As a result of inadequate environmental control coupled with growth in the industrial use of heavy metals, contaminated ingredients have been introduced into the food production process. Irrespective of the origin of the metals in the soil, excessive levels of many metals can result in soil quality degradation, crop yield reduction, and poor quality of agricultural products, posing significant hazards to human, animal, and ecosystem health [13].

Although some individuals are primarily exposed to heavy metals on the job, the main route of exposure to these toxic elements for most people is through the diet [14].

Food Safety in China: Science, Technology, Management and Regulation, First Edition.
Edited by Joseph J. Jen and Junshi Chen.

Presence in the food chain increases the risk for dietary exposure to these metals and increases the risk for resultant adverse health effects. In fact, according to World Health Organization (WHO)-issued reports, dietary exposure to lead and cadmium were two main health concerns posed to the Chinese population [15, 16]. Environmentally contaminated edible agricultural products and processed foods are the potential primary sources of food contamination currently in China. The primary sources of food contamination can occur during any step of the food processing cycle from farm to table including:

1) Environmental contamination of raw food. Food ingredients can be directly or indirectly contaminated during the growing season;
2) During the transport of raw materials to processing factories;
3) During the manufacturing process. Processed food can become contaminated with heavy metals migrating from food additives or leaching from food contact materials/packages, detergents, and disinfectants;
4) During the transport of packaged food;
5) While packaged food is being stored and distributed [17].

15.1 Food Safety Concerns in the Past

15.1.1 Contamination of Soil

Heavy metals contamination in soil is a critical component of an ecosystem which sustains life. Anthropogenic sources such as those stemming from mining, industrial, and urban activities can introduce heavy metals into soils [18, 19]. The resulting contamination can be driven by factors such as air and water deposition of industrial emissions, downslope movement of mineral-rich rocks, corrosion of metal structures, metal-containing agricultural fungicides, and intentional and incorrect handling of mineral-rich waste such as paints and industrial chemicals [18]. The resulting contamination of soils and water can either be extensive or localized [19].

A soil study conducted in the USA compared analytical data from background soils and soils affected by anthropogenic contamination from various sources (urban, agricultural, mining, or smelting activities) reported the following median total concentrations: cadmium (0.16 and 0.22 mg/kg), lead (10, 48 and 73 mg/kg), and mercury (44 and 170 mg/kg) [19]. Table 15.1 gives the median and maximum concentrations of heavy metals from surveys in different countries and regions and also average values for these elements in world soils [19–27]. The variation of heavy metals between countries and regions not only reflects differences in geochemical composition of the soil parent material, but also the degree of soil contamination from various sources [18].

Table 15.2 lists the different anthropogenic sources of heavy metals contaminating soils annually in the world. The three main sources of heavy metal contamination are coal ash, commodity impurities such as those dumped in landfills, and atmospheric deposition from coal and oil-fired electricity generating stations, and so on [28, 29]. However, although more localized (a few km), atmospheric deposition tends to be the most extensive form of contamination because long-range transport can result in particles being carried thousands of kilometers [28].

Table 15.1 Median and maximum total heavy metal concentrations in topsoil in various countries and average values for world soils (mg/kg).

	Europe [20]	Baltic States [21]	Ireland [22]	England and Wales [23]	Netherland [24]	NL(bkgd)[a] [24]	Denmark [25]	N. California [26]	USA [27]	World (av)[b] [19]
No. of samples	852	773	1,310	5,692	100	100	393	1,300	1,903	–
As	6.0(<27.3)	1.9(<24)	7.25(<123)	–	5.6(<39)	20	3.3(<48)	6.0(<106)	–	4.7
Cd	0.145(<14)	0.13(<1.1)	0.326(<15)	0.7(<41)	0.14(<2.5)	0.6	0.16(<0.85)	0.2(<11.2)	0.16(<41)	1.1
Hg	0.037(<1.35)	–	0.086(<3.5)	–	0.045(<1.2)	0.15	–	–	0.075(<3)	0.1
Pb	15(<886)	8.4(<76)	24.8(<2,635)	40(<16,338)	15.6(<451)	50	11.3(<102)	23(<2,354)	10.1(<1,650)	25

a) Official background concentration for the Netherlands.

b) Average concentrations for world soils [38].

Sources of information for this tables are in references, [19–27].

Dash Lines (–) indicates no results were available.

Table 15.2 Different sources of heavy metals contaminating soils annually in the world (1000 tonnes/yr).

Sources	As	Cd	Hg	Pb
Agriculture and food waste	0~0.6	0~0.3	0~1.5	1.5~27
Farmyard manure	1.2~4.4	0.2~1.2	0~0.2	3.2~20
Logging and timber	0~3.3	0~2.2	0~2.2	6.6~8.2
Industrial waste	0.09~0.7	0.88~7.5	0~0.26	18~62
Municipal sludge	0.01~0.24	0.02~0.34	0.01~0.8	2.8~9.7
Organic waste	0~0.25	0~0.01	–	0.02~1.6
Metal processing solid waste	0.01~0.21	0~0.08	0~0.08	4.1~11
Coal ash	6.7~37	1.5~13	0.37~4.8	45~242
Fertilizer	0~0.02	0.03~0.25	–	0.42~2.3
Marl	0.04~0.5	0~0.11	0~0.02	0.45~2.6
Commodity impurities	36~41	0.78~1.6	0.55~0.82	195~390
Atmospheric deposition	8.4~18	2.2~8.4	0.63~4.3	202~263
Total	52~112	5.6~38	1.6~15	479~1113

(–) indicates no results were available.

Table 15.3 The content of heavy metals in the agricultural soils (mg/kg).

Country	Pb	Cd	Hg	As
Spain	213.93	1.42	–	–
America	23.00	0.78	–	–
Korea	5.25	0.12	0.05	0.78
Slovakia	139.00	–	–	–
USA	55	13.5	–	–
India	0.95	0.82	–	–
Iran	5.17	0.34	–	–

(–) indicates no results available.

Table 15.3 lists the content of heavy metals in agricultural soils from around the world [28]. The major sources of heavy metal contamination in agricultural soils were again anthropogenic sources (smelting, waste treatment, mining, sewage sludge, automobile exhaust, fertilizers, and pesticides, etc.). The heavy metals in the soil are then absorbed and accumulated by crops used for human consumption [29].

The above data show that heavy metal contamination is a severe global problem. Although the presence of heavy metals on earth is a natural phenomenon, their enhanced levels are mainly caused by anthropogenic activities. The increased circulation of these heavy metals through soils, water, and air, and their inevitable transfer to the human food chain, remains an important environmental issue which can pose a serious health risk for future generations.

According to the food safety monitoring efforts in recent years, food grown in China poses a major threat of heavy metal contamination. Due to rapid economic development and neglectful environmental protection, pollution is the major source of heavy metal contamination in food currently in China [30–32]. According to the Bulletin on the National Survey of Soil Contamination (2014), jointly released by the Ministry of Environmental Protection and the Ministry of Land Resources of China, nearly 4 million hectares of arable land have been contaminated at the moderate to severe level, which accounts for about 2.9% of China's arable land. This land contains soil with Cd, Ni, Cu, As, Hg, and Pb exceeding recommended levels. Sources of dietary exposure vary across provinces and some provinces are more heavily polluted than others.

15.1.2 Lead in Century Eggs

According to the results of the 2007 Total Diet Survey (TDS) conducted in China, eggs and related products, cereals, vegetables, and wild yams (i.e., *Dioscorea villosa)* were the main sources of dietary exposure to lead for the general population [33]. In coastal provinces, aquatic animals and related products contributed substantial amounts of lead, while the contribution of meat and beans to lead exposure were significant sources in other provinces [34]. At one time, century eggs were a major food for higher concentrations of lead.

As a traditional Chinese food, century eggs were made according to a special processing method. Eggs were covered with a mixture of alkaline materials such as clay, ash, quicklime, and rice hulls for several weeks or months. When using traditional processing methods, red lead, which contains lead oxide, was one of the key materials used to block the pores in the shells of century eggs. Due to migration of this mixture through the eggshell, the edible part of the century egg became highly contaminated with lead and as such represented a potential health risk for people in China. According to 2000-2006 data from the China Food Safety Monitoring System, the average concentration of lead in century eggs exceeded 1 to 2 mg/kg.

Subsequent to the issuance of an early food safety risk warning, the processing techniques were gradually changed and red lead was replaced by new chemicals, such as copper sulfate or zinc sulfate. Hence, from 2006 to 2010, the lead content in century eggs gradually decreased to safer levels (see Figure 15.1). When the revised National Food Safety Standard for Food Contaminant Limits (GB 2762-2012) came into effect, the maximum level of lead in century eggs was limited to 0.5 mg/kg. Producers were urged to make more effort to reduce lead levels in the products, resulting in a further decrease in average concentrations to 0.2 mg/kg. These data show that the promulgation and implementation of the new process with new chemicals resulted in substantial reductions in the levels of lead in century eggs.

15.1.3 Cadmium in the Kidneys of Livestock and Poultry

Cadmium absorbed by livestock and poultry would mainly accumulate in their liver and kidneys. In particular, the kidney is the target organ for cadmium, and concentrations of cadmium in offal, especially kidney, is higher than in the muscles. Kidney from livestock and poultry is always used as food in China, so cadmium contamination could be delivered through the food chain. The maximum limits for cadmium in the kidneys and liver of livestock and poultry were confined to 1.0 mg/kg and 0.5 mg/kg, respectively,

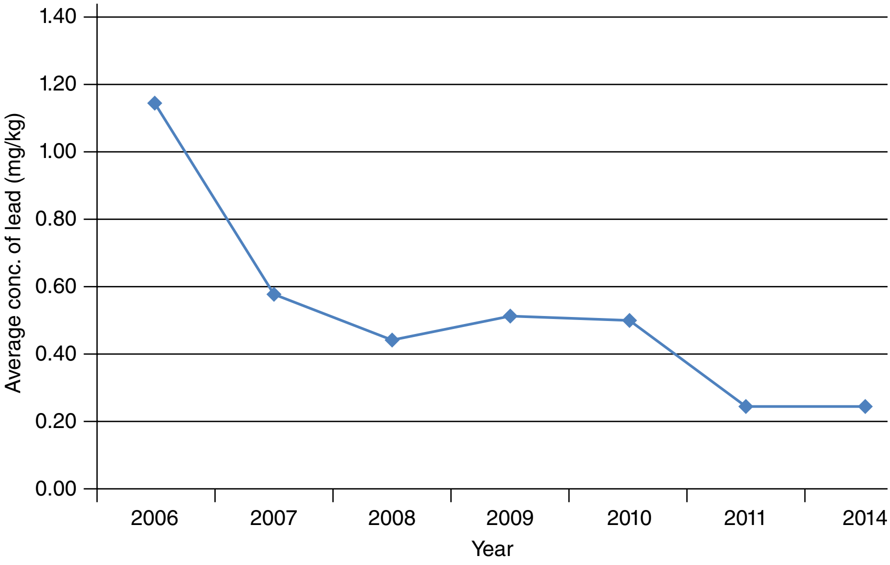


Figure 15.1 Trend of average lead levels in century eggs from 2006 to 2014.

according to the National Food Safety Standard Food Contaminant Limits (GB 2762-2012). Cadmium levels in kidney were systematically monitored in China from 2009 to 2014, and the rate of samples exceeding the limits decreased from more than 6% to about 3%. Obvious regional differences could be observed between high cadmium pollution areas and non-pollution areas. Taking a person from a high cadmium pollution province as an example, the average concentration of cadmium in their kidney was 0.7 mg/kg in 2014, 10% of the samples exceeded the maximum limit of cadmium, while the average concentration of cadmium in a kidney from a non-polluted area was 0.3 mg/kg. The regional distribution of cadmium contamination is basically identical to the cadmium concentration in rice (see Figure 15.2).

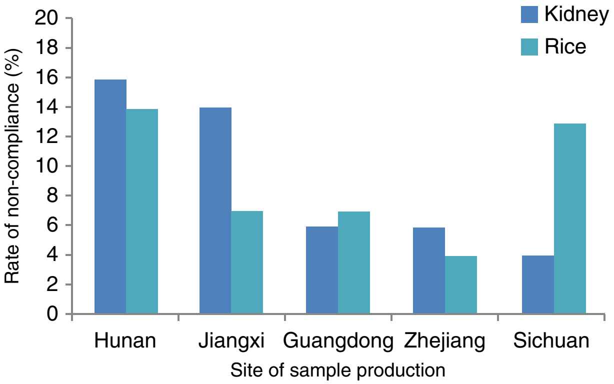


Figure 15.2 Geographic distribution of cadmium contamination in rice and kidney.

15.1.4 Mercury in Special Kinds of Fish

Mercury is a naturally occurring metal and exists mainly in three forms: the metallic element, inorganic salts, and organic compounds. Inorganic mercury is biomethylated in water to form methylmercury. Approximately 85% of methylmercury is ingested by aquatic organisms (e.g., shellfish, predatory fish, sea mammals). Human mercury exposure occurs primarily through inhalation of elemental metallic mercury or through ingestion of organic mercury compounds from contaminated foods, particularly seafood. Mercury exposure has become an important health concern. As a result, mercury surveillance in key foods, such as fish and seafood, is important. In the 1950s, Minamata disease,[1] which is a "pollution disease," occurred in Japan due to the intake of polluted fish contaminated with methylmercury [35, 36]. Methylmercury can make organisms at the top of the food chain reach a high level of mercury content through bioaccumulation in the food chain and magnified effects [37–39]. Human mercury exposure occurs primarily through inhalation of elemental metallic mercury or through ingestion of organic mercury compounds from contaminated foods, particularly seafood. Because of the bioaccumulation of organic mercury compounds in the tissues of predatory fish, considerable human exposure occurs when these fish are consumed as part of the diet [40]. The content of mercury in processed products with carnivorous fish as the raw material is also higher. Marine fish, especially predatory fish, for instance swordfish and tuna, which are at the top of the food chain, often have a higher concentration of methylmercury. The maximum limit for methyl mercury in GB 2762-2012 was set at 1.0 mg/kg for predatory fish and 0.5 mg/kg for other fish. According to the monitoring data in recent years, only a few samples exceed the maximum limit. However, aquatic products such as dried fish floss produced using sword fish and tuna fish may have high concentrations of mercury [38, 39].

15.1.5 Arsenic in Rice

Arsenic levels differ greatly according to plant variety and planting area. Compared to other crops, rice has been shown to absorb and accumulate arsenic easily. Rice is a primary source of inorganic arsenic exposure in China's food system. According to 2014 monitoring results, nearly 5% of rice samples had arsenic concentrations higher than 0.2 mg/kg, although as a percentage of the total arsenic in rice, inorganic arsenic levels were acceptable [41]. The Committee on Contaminants in Foods (CCCF) put forward the issue of arsenic control in rice. International standards for inorganic arsenic in rice were drafted by China and approved by the Codex Alimentarius Commission (CAC). Maximum limits of inorganic arsenic in cereals and cereal supplemental foods for infants were set accordingly by the GB 2762-2012 Standard. The maximum limit of inorganic arsenic in rice was set at 0.2 mg/kg. Algae and algae products are another source of arsenic exposure, but most of the arsenic exists in the organic form, which has little to no toxicity.

---

[1] Minamata disease in Japan in the 1950s was caused by methylmercury poisoning from fish and shellfish contaminated by mercury discharges. It is a neurological syndrome including ataxia, numbness in the hands and feet, general muscle weakness, narrowing of the field of vision, and damage to hearing and speech.

15.2 Heavy Metal Contamination at Present

15.2.1 Lead

Lead is a naturally occurring metal; however, because of human activities including mining, farming, and manufacturing, higher levels of lead are found everywhere in the environment. Exposure to lead occurs via inhalation of lead-contaminated dust particles or aerosols, and ingestion of lead-contaminated food and water. Lead that is not excreted remains in the blood and binds to red blood cells, is distributed throughout the organs, and ultimately accumulates in the teeth, bones, brain, liver, and kidneys. Dietary intake is a major source of lead exposure. According to the WHO, adverse health effects associated with lead contamination in food and subsequent dietary exposure to lead poses a major health concern for the Chinese population. Therefore, lead surveillance in foods, and promulgation and implementation of new processes to decrease lead content in food should be implemented as needed.

As infant formula is an alternative to human milk for infants, its safety is very important. Because of its toxicity, the limit for lead in infant formula is getting lower and lower. For example, the General Standard for Contaminants and Toxins in Food and Feed (Codex Standard 193-1995) was amended in 2015, with the purpose of protecting infants. In this standard, the maximum level for lead in infant formula, formula for special medical purposes intended for infants, and follow-on formula decreased from 0.02 mg/kg to 0.01 mg/kg.

Vegetables are an important food group that shows lead contamination. Lead in vegetables mainly comes from contaminated soil and water. Lead contamination can cause a reduction in transpiration, disruption to the plant water balance, a decrease in chlorophyll production, and can result in adverse effects on photosynthesis, lamellar organization of the chloroplast, and cell division [42]. Stem vegetables (celery), leafy vegetables (spinach), bulb vegetables (garlic, onion), brassica vegetables (cabbage, cauliflower), root and tuber vegetables (potato), bean vegetables, and solanaceous vegetables (tomato, eggplant) consumed by the Chinese population may be contaminated with varying levels of lead, depending on where the vegetables were grown. According to recent survey results for vegetables, lead contamination may be especially notable in the Yunnan and Henan Provinces. Yunnan Province is rich in mineral resources, and soil surrounding the mining areas has been contaminated; because of mining activities, about 10% of the vegetable samples surveyed from 2013 to 2014 were contaminated with lead concentrations exceeding the national maximum limit, listed in Table 15.4. Except the levels for potato, livestock and poultry meat, milk, and fish, the national maximum limits are consistent with the standards of the CAC, the EU, Australia and New Zealand [43].

15.2.2 Cadmium

Cadmium is generally present in the environment at low levels; however, human activity has greatly increased these levels. In addition to tobacco smoke, food is a major source of cadmium exposure. Inorganic cadmium salts, formed from cadmium ions, are absorbed by plants via the roots and transported to the edible leaves, fruits, and seeds. Cadmium is also found in seafood, including mollusks and crustaceans [14]. Cadmium absorbed by livestock and poultry mainly accumulates in the kidneys. Because kidney

Table 15.4 Maximum limit of lead in vegetables (mg/kg).

Food category	Maximum limit
Brassica vegetables, leafy vegetables	0.3
Legume vegetables, dioscorea	0.2
Other vegetables	0.1

from livestock and poultry is commonly used as food in China, potential for exposure to humans exists.

It is readily accumulated in aquatic organisms and cereals, which may lead to cadmium contamination in rice and seafood. Japan and China have higher levels of environmental cadmium, and exposure is comparatively higher than in other countries [44]. Thus, cadmium exposure has become an important health concern in some parts of China. Peanuts, lettuce, and spinach are plants that are known to easily accumulate cadmium, whereas milk, potatoes, some fruit, and meat may have lower levels. Levels of cadmium in drinking water tend to be low and are of less concern than food sources [45].

15.2.2.1 Infant Food

For the purpose of protection, Commission Regulation (EC) No 1881/2006 set maximum levels for infant food from January 1,2015. These were the first levels that were set for cadimum specifically in infant food in the world: 0.010 mg/kg for powdered formulae manufactured from cow's milk protein or protein hydrolysates; 0.005 mg/kg for liquid formulae manufactured from cow's milk protein or protein hydrolysates; 0.020 mg/kg for powdered formulae manufactured from soya isolates, alone or in a mixture with cow's milk protein; 0.010 mg/kg for liquid formulae manufactured from soya isolates, alone or in a mixture with cow's milk protein; 0.040 mg/kg for processed cereal-based foods and baby foods for infants and young children.

15.2.2.2 Rice

Rice is the main crop planted in some provinces of China, including Hunan, Guangdong, Yunnan, and Sichuan. In these provinces, rice is contaminated by cadmium due to local soil contamination, with levels in rice for human consumption often exceeding 0.2 mg/kg. Because of the importance of rice to the Chinese diet, the maximum limit of cadmium in rice in China is set at 0.2 mg/kg, which is half the level prescribed by the Codex standard (0.4 mg/kg).

Uptake and accumulation of cadmium in rice is positively correlated with levels of cadmium in soil and irrigation water. Accumulation of cadmium in rice fields depends on soil conditions that regulate cadmium mobilization from soil, including soil pH, levels of micronutrients (e.g., manganese, zinc), and irrigation practices. The mobility and absorption rate of cadmium into crop plants increases in soils with higher acidity. Irrigation water influences the redox status of soil, which also influences uptake of cadmium into plants. Cadmium absorption increases under aerobic conditions and decreases under anaerobic conditions, because cadmium readily precipitates as sulfides under anaerobic conditions.

Hunan Province, with its rich mineral resources, is known as the "land of rice and fish" and the "land of non-ferrous metals." The region has a long history of mining, including lead-zinc and copper-zinc mines. Abandoned mines in this province have caused severe heavy metal contamination of water, soil, and crops along the Xiangjiang River, especially cadmium and arsenic. Until 2013, 24% of the cultivated land and 27% of the irrigation water in Hunan Province was polluted by heavy metals. Based on the results of monitoring conducted in 2013–2014, the average nationwide rate of cadmium in rice exceeding regulatory limits was about 3%; however, the rate of cadmium in rice exceeding national limits is above 10% in Hunan Province and more than 5% in Sichuan and Guangdong Provinces. While the rate of cadmium in rice exceeding the national limit was less than 1% in other provinces, over 80% of samples exceeded the maximum limit according to data collected from severely contaminated areas of Changsha, Zhuzhou, Xiangtan, and Chenzhou in Hunan Province. The average level of cadmium was 0.7 mg/kg and the maximum level was 4 mg/kg.

15.2.2.3 Aquatic Animals

Aquatic animals are another food source impacted by environmental cadmium contamination. Cadmium is released by the weathering of rocks into aquatic systems, which plays a significant role in the global cadmium cycle. With regard to aquatic ecosystems, weathering and erosion have resulted in large quantities of cadmium being transported via rivers to oceans, which now act as large natural reservoirs of cadmium. Aquatic and marine organisms, such as mollusks, crustaceans, and seaweed, are the most likely organisms to be contaminated with cadmium. Maximum limits of cadmium in aquatic animals and products in the China National Food Safety Standard (GB 2762-2012) are listed in Table 15.5.

According to survey data collected in recent years, crustaceans, especially sea crabs from some of the coastal provinces of China, were contaminated by cadmium. During 2013 and 2014, sea crabs from Zhejiang, Shandong, Guangdong, and Jiangsu Provinces of China were reported to be contaminated by cadmium, and over 20% of the sea crab samples exceeded the maximum limit of cadmium, with an average concentration of about 0.9 mg/kg. As an example, in Zhejiang Province, about 50% of the sea crab samples had concentrations exceeding the maximum limit, with an average content over 1.5 mg/kg. However, the cadmium levels in freshwater crabs were lower than those in sea crabs, with less than 5% of the freshwater crab samples contaminated by cadmium at concentrations exceeding the maximum limit. While higher cadmium levels were also reported in mollusks, such as bivalves, gastropods, cephalopods, and echinoderms, with average concentrations over 0.4 mg/kg, the rate exceeding the maximum limit was less than 5%.

Table 15.5 Maximum limit of cadmium in aquatic animal and product (mg/kg as cadmium).

Food Category	Maximum Limit
Fish	0.1
Crustaceans	0.5
Bivalves, gastropods, cephalopods, echinoderms	2.0

15.2.3 Arsenic

Arsenic is a heavy metal found in soil and surface water in the form of inorganic arsenic and organic arsenic. Inorganic arsenic, which exists as arsenite (As [III]) and arsenate (As[V]), is more toxic than organic arsenic. Organic arsenic includes methylarsenate, arsenic acid dimethyl, trimethylarsenic arsenic oxide, arsenocholine, arsenobetaine. Methylarsenate and arsenic acid dimethyl are more toxic than trimethylarsenic arsenic oxide, while arsenocholine and arsenobetaine have only little or no toxicity.

The dietary source of arsenic for Chinese adults was quite different from foreign research results due to different dietary structures. Aquatic animals and their products are the main source of dietary intake of arsenic in Western countries, while cereal and cereal-based food were the main source in China. The research results from Guangdong and Zhejiang Provinces in China also showed that cereals, aquatic animals, and their products were the main sources of dietary exposure. However, further health risks could not be analyzed because systematic inorganic data were absent and because of the toxicities of different forms of arsenic.

15.3 Prospects for Heavy Metal Contamination Control

Environmental contamination by heavy metals is a serious and worldwide problem that accompanies rapid industrialization and urbanization in many countries and has resulted in complex environmental issues in China as well [12, 46, 47]. Chemical pollution is a major threat to both agricultural land (e.g., the food chain) and water supplies, which in turn, pose a major risk to public health [48]. Long-term sustainable resolutions to heavy metal contamination and the resulting health concerns include the implementation of public policies and international countermeasures to both mitigate current risks and prevent further contamination of air, soil, food, and water. The primary objective of such countermeasures is to increase the elimination of heavy metals as a source of contamination and to prevent or decrease further threats of toxicity. First and foremost, pollution control through regulation and legislation should be strengthened to reduce the level of heavy metals in soil and water. Through 2011, the Chinese Government approved two significant plans to reduce pollution by heavy metals including the "12th Five-Year Plan on Prevention and Control of Heavy Metal Pollution" and the "Xiangjiang River Basin Control Plan for Heavy Metal Pollution" [49, 50]. Additionally, recent progress to lessen water pollution through the construction of waste treatment plants has resulted in reported reductions in emissions of arsenic and mercury to water [47].

In addition to elimination of heavy metals, immediate measures should be put in place to block the migration of metals where pollution is significant. Such efforts include the planting of low or non-enriched plant varieties [51] and amending characteristics of the soil with zinc or selenium to slow/lessen the uptake of heavy metals [52]. Additional efforts should be based on providing farming, breeding, and fishing guidelines for polluted areas, which include recommendations on planting mode and crop selection. Agricultural planting structure should be adjusted and crop varieties with low or negligible metal uptake should be promoted in cadmium-polluted areas [50]. The procedures used for cadmium contamination management of rice in Japan could be useful to China when planning and implementing cadmium controls [53].

Because of the potential for bioaccumulation and the resultant toxicity, levels of heavy metals in contaminated areas should be subject to mandatory monitoring. But these exposure measurements of contaminated areas (e.g., heavy metals in soil, river basins, and water reservoirs) are essential for the protection of high-risk populations and subgroups and should be shared between the various governmental departments (e.g., agricultural, food safety, environmental protection).

Food safety risk monitoring should be systematic and ongoing and result in the collection of data necessary to assess food-borne disease, food contamination, and other hazard factors related to the food chain. The 2009 Food Safety Law was critical in establishing food safety policy and in adopting international standards. Additionally, the China National Center for Food Safety Risk Assessment, established in 2011, has been charged with coordinating national efforts to monitor chemical factors [12]. Contamination in food could be effectively controlled through monitoring of heavy metals in food and trace analysis should be conducted. Measures should be taken to control and eliminate the pollution.

There should be a dedicated focus on susceptible populations and prevention of health hazards. Exposure measurements are essential for the protection of high-risk populations. Furthermore, governments should consider susceptible populations when setting acceptable levels or criteria related to chemicals. Children are particularly vulnerable and at risk for neurotoxic effects caused by lead due to higher gastrointestinal absorption and blood–brain barrier permeability. Special monitoring should be conducted for children and pregnant women in the polluted areas, such as blood levels of lead and cadmium.

In all, significant time and effort should be devoted to the management of environmental heavy metal pollution. Although heavy metal contamination in food will exist to a certain extent, human health will be protected effectively only if principles of treating both the symptoms and the root causes are followed, and prevention and control efforts are added.

References

1 Morris C (Ed.). (1992) *Academic Press Dictionary of Science and Technology*. San Diego: Academic Press.

2 Adal A, Wiener SW. (2015) Heavy metal toxicity. WebMD Health Professional Network and Medscape Website: http://emedicine.medscape.com/article/814960-overview (Accessed December, 2015).

3 Tchounwou RB, Yedjou CG, Patlolla AK, Sutton DJ. (2012) Heavy metals toxicity and the environment. In: Luch A (Ed.), *Molecular, Clinical and Environmental Toxicology*. Volume 3; 101 in the Experientia Supplementum Series:133–164.

4 World Health Organization (WHO) (2011). Cadmium in drinking-water. Background document for development of WHO Guidelines for Drinking-water Quality.

5 Hogan, C. M. (2009). Heavy metal. In: E. Monosson and C. Cleveland (Eds.), *Encyclopedia of Earth*. Washington, DC: National Council for Science and the Environment.

6 Järup L. (2003) Hazards of heavy metal contamination. *Br Med Bull.* 68:167–182.

7 Duffas JH. (2002) Heavy metals: a meaningless term? *Pure Appl. Chem.* 74(5):793–807.

8 Dorne JC, Kass GE, Bordajandi LR, Amzal B, Bertelsen U, Castoldi AF, Heppner C, Eskola M, Fabiansson S, Ferrari P, Scaravelli E, Dogliotti E, Fuerst P, Boobis AR, Verger P. (2010) Human risk assessment of heavy metals: Principles and applications. *Metal Ions in Life Sciences.* 8:27–60.

9 Jaishankar M, Tseten T, Anbalagan N, Mathew BB, Beeregoeda KN. (2014) Toxicity, mechanism and health effects of some heavy metals. *Interdiscip Toxicol.* 7(2):60–72.

10 He ZL, Yang YE, Stoffella PJ. (2005) Trace elements in agroecosystems and impacts on the environment. *J. Trace Elem. Med Biol.* 19(2–3):125–140.

11 Singh R, Gautam N, Mishra A, Gupta, R. (2011) Heavy metals and living systems: An overview. *Indian J Pharmacol.* 13(3):246–253.

12 Lam HM, Remas J, Fung MC, Xu, L., Sun, SS. (2013) Food supply and food safety issues in China. *Lancet.* 381:9882.

13 Long X, Yang XE, Ni WZ. (2002) Current status and prospects on phytoremediation of heavy metal polluted soils. *J Appl Ecol.* 13:757–762.

14 Morais S, Garcia e Costa F, Pereira ML. (2012) Heavy metals and human health. In Oosthuizen J (Ed.), *Environmental Health: Emerging Issues and Practice.* http://cdn.intechweb.org/pdfs/27687.pdf (accessed December, 2015).

15 World Health Organization (WHO) (2010) Exposure to lead: a major public health concern. WHO website: http://www.who.int/ipcs/features/lead.pdf (Accessed December, 2015).

16 World Health Organization (WHO) (2010) Exposure to cadmium: a major public health concern. WHO website: http://www.who.int/ipcs/features/lead.pdf (Accessed December, 2015).

17 Nerín C, Aznar M, Carrizo D. (2016) Food contamination during food process. *Trends Food Sci Technol.* 48, 63–68.

18 Alloway BJ (Ed.) (2013) *Heavy Metals in Soils: Trace Metals and Metalloids in Soils and their Bioavailability*, Third Edition, Volume 22, Springer.

19 Burt R, Wilson, MA., Mays, MD, Lee CW. (2003) Major and trace elements of selected pedons in the USA. *J. Environ. Qual.*, 32:2109–2121.

20 Bak J, Jensen J, Larsen MM, Pritzl G, Scott-Fordsmand J. (1997) A heavy metals monitoring-programme in Denmark. *Sci.Total Environ.* 207 (2):179–186.

21 Burt, R, Wilson, MA, Mays, MD, Lee, CW. (2003) Major and trace elements of selected pedons in the USA. *J. Environ. Qual.*, 32:2109–2121.

22 Brus DJ, Lamé FP, Nieuwenhuis RH. (2009) National baseline survey of soil quality in The Netherlands *Environ. Pollut.* 157(7):2043–2052.

23 Goldhaber MB, Morrison JM, Holloway JM, Wanty RB, Helsel DR, Smith DB. (2009) A regional soil and sediment geochemical study in northern California. *Appl. Geochem.* 24:1482–1499.

24 Kabata-Pendias A. (2001) *Trace Elements in Soils and Plants*, Third Edition. Boca Raton: CRC Press.

25 McGrath SP, Loveland PJ. (1992) *Soil Geochemical Atlas of England and Wales.* Glasgow: Blackie Academic and Professional.

26 Reiman C, Siewers U, Tarvainen T, Bityukova L, Eriksson J, Gilucis A, Gregorauskiene V, Lukashev V, Matinian N, Pasieczna A. (2003) *Agricultural Soils of Northern Europe: A Geochemical Atlas.* Schweizerbartsche Verlagsbuchhandlung, Stuttgart.

27 Salminen R. (2005) *Foregs Geochemical Atlas of Europe*, EuroGeoSurveys. http://weppi.gtk.fi/publ/foregsatlas/ForegsData.php (accessed November 2016).

28 Chao S, LiQin Ji, WenJun Z. (2014) A review on heavy metal contamination in the soil worldwide: Situation, impact and remediation techniques. *Environ Skeptics Critics*, 3(2):24–38.

29 Nriagu JO, Pacyna JM. (1988) Quantitative assessment of world-wide contamination of air, water and soils by trace metals. *Nature*, 333:134–139.

30 Zhou J, Zhou Ju, Feng R. (2014) Remediation of Heavy Metal Pollution in Soil. *Bull. Chin. Acad. Sci.* 315–320 [in Chinese].

31 Wang L, Zhang M. (2007) Release behaviors of heavy metals from polluted soils with heavy metals of different sources. *Res. Environ. Sci.* 4:134–138 [in Chinese].

32 Liang C, Chen Z, Liu M. (2002) Study Processes On Heavy Metal Pollution On Vegetables. *Hunan Agri. Sci.*. 4:45–48 [in Chinese].

33 Li X. (2012) *Dietary Exposure Assessment of Elements Using Total Dietary Survey in China*. Beijing: Chinese Center for Disease Control and Prevention [in Chinese].

34 Li X, Liu Q, Liu L, Wu Y. (2012) Application of the data from China Total Diet Study to assess the distribution of lead exposure in different age-gender population groups. *J. Hygiene Res.* 41(3):379–384 [in Chinese].

35 Murata K, Sakamoto M. (2011) Minamata Disease. *Encyclopedia of Environmental Health*, 774–780.

36 Mcalpine D, Araki S. (1958) Minamata Disease: An unusual neurological disorder caused by contaminated fish. *Lancet*, 272(7047):629–631.

37 Zhu A, Zhang W, Xu Z., Huang L, Wangle W. (2013) Methylmercury in fish from the South China Sea: Geographical distribution and biomagnification. *Marine Poll. Bull.* 77(1–2):437–444.

38 Kehrig HA, Howard BM, Malm O. (2008) Methylmercury in a predatory fish (*Cichla* spp.) inhabiting the Brazilian Amazon. *Environ Pollut.* 154(1):68–76.

39 Herreros MA, Iñigo-Nuñez S, Sanchez-Perez E, Encinas T,Gonzalez-Bulnes A. (2008) Contribution of fish consumption to heavy metals exposure in women of childbearing age from a Mediterranean country (Spain). *Food Chem. Toxicol.* 46(5):1591–1595.

40 Bernhoft RA. (2012) Mercury toxicity and treatment: a review of the literature. *J Environ Public Health.* 460–508.

41 Li X, Gao J, Wang Y, Chen J. (2006) Chinese total dietary survey in 2000-intake of arsenic. *J. Hygienic Res.* 35(1):63–66 [in Chinese].

42 Pourrut B, Shahid M, Dumat C, Winterton P, Pinelli E. (2011) Lead uptake, toxicity, and detoxification in plants. *Rev. Environ. Contam. Toxicol.* 213:113–136.

43 Shao Yi, Wang Jun, Wu Yongning. (2014) Study on current situation and development trends of domestic and foreign lead maximum level standards in food. *J. Food Safety Qual.* 5(1):294–299 [in Chinese].

44 Sanders T, Liu Y, Buchner V, Tchounwou PB. (2009) Neurotoxic effects and biomarkers of lead exposure: A review. *Res Environ Health.* 24:15–45.

45 Krzywy I, Krzywy E, Peregud-Pogorzelskf J, Juksza K, Brodkiewicz, A. (2011) Cadmium: Is there something to fear? *Annal. Acad. Med. Stetin.* 57(3):49–63.

46 Gong P, Liang S, Carlton EJ, *et al.* (2012) Urbanisation and health in china. *Lancet.* 379:843-852.

47 Jiang M, Zeng G, Zhang C, Ma X, Chen M, Zhang J, Lu L, Yu Q, Hu L, Liu L. (2013) Assessment of heavy metal contamination in the surrounding soils and surface sediments in Xiawangang River, Qingshuitang District. *PLoS ONE* 8(8):e71176.

48 Zhang J, Mauzerall DL, Zhu T, Liang S, Ezzati M, Remals JV. (2010) Environmental health in China: progress towards clean air and safe water. *Lancet* 375:9720.

49 Hu H, Jin Q, Kavan P. (2014) A study of heavy metal pollution in china: Current status, pollution-control policies and countermeasures. *Sustainability* 6:5820–5838.

50 Zhi Y, Sun T, Zhou Q, Zhu Y. (2015) Identification of Chinese soybean cultivars with low lead accumulation and the effect of lead on their mineral ion complement. *Acta Sci. Circum.*w 35(6):1939–1945 [in Chinese].

51 Wang Y, Chen N, Liu C, Wang X, Zhou D, Wang S, Chen H. (2015) Effective measures to prevent heavy metal pollution: Management and control methods based loading capacity of soil: To International Year of Soils, IYS 2015. *J. Agro-Environ Sci.* 4:613-618 [in Chinese].

52 Corguinha A, Goncalves V, Souza G, Lima W, Penido E, Pinto C, Francisco E, Guiherme L. (2012) Cadmium in potato and soybeans: Do phosphate fertilization and soil management systems play a role? *J. Food Comp. Anal.* 27(1):32–37.

53 Bolan NS, Makino T, Kunhikrishnan A, Kim PJ, Ishikawa M, Naidu R, Kirkham MB, Bolan NS. (2013) Cadmium contamination and its risk management in rice ecosystems. *Adv Agron.* 119:183–273.

16

Food Fraud

Yongning Wu[1], Hong Miao[1], Bing Shao[2], Jing Zhang[2], John W. Spink[3] and Douglas C. Moyer[3]

[1] *China National Center for Food Safety Risk Assessment, Beijing, China*
[2] *Beijing Center for Disease Prevention and Control, Beijing, China*
[3] *Michigan State University, USA*

16.1 Introduction

Food fraud, including the US Food and Drug Administration (FDA) defined sub-category of economically motivated adulteration (EMA), refers to illegal deception for economic gains using food. This includes the intentional addition of non-authentic substances, substitutes, and illegal additives, or the removal or replacement of authentic substances in food, food ingredients and food packaging, or tampering, false declaration, or making a false or misleading statements about food [1, 2]. When dealing with food fraud, most consumers are concerned with EMA, which is one of the important factors that affect and undermine food safety, and food security, and may cause disturbance of society stability. While some food fraud does not cause health hazards, the potential risk to food safety is present, and may endanger the health of consumers.

Since the dawn of trading and commerce, food fraud has accompanied a change in social and economic patterns. As the American writer Bee Wilson wrote, “Food fraud has a long history, and it is mixed up with all the other forces – scientific, economic, political – that went together, for the better and worse, to create the world we live in.” [3] Food fraud was recorded in Roman times, including when lead was added to sweeten wines. Since then, there has been a wide range of food frauds including: watered milk, flour mixed with chalk powder, adulterated olive oil, the Blackthorn Company made fake tea leaves after dyeing materials such as stems or waste products, the recent horse meat crisis in Europe, and wine fraud [4–6].

The earliest incident of food fraud in China is difficult to determine, but there are several historical references. During the Zhou Dynasty (1046 to 256 BC), *The Book of Rites* was the earliest record of the food safety management in China. It stated, “Grains not in-season, immature fruit, cannot be vended.” There were less formal mentions of food fraud prior to the Zhou Dynasty. Yuan Cai was an official, author, poet, and scholar from the Song Dynasty (960 to 1279 AD). In his book *Yuan Shi Fan*, he described

Food Safety in China: Science, Technology, Management and Regulation, First Edition.
Edited by Joseph J. Jen and Junshi Chen.

specific instances of food fraud, such as "Chickens with sand in the body, inflated geese and sheep, salt mixed with ash, silk products with glue paste, rice and wheat with increased moisture, meat with irrigation water, medicinal herbs substituted by something else." The eighth king of the Song Dynasty, Song Huizong, noted in the *Treatise on Tea*, "Some tea makers who seek huge profit use the baked white tea sprout to substitute for tea from Beiyuan, and some even use the crushed powder made from tea cakes with the packaging of Beiyuan tea to substitute for real Beiyuan tea." In the Ming Dynasty (1368 to 1644 AD) Wu Luzhen wrote that "Somebody satirized the fraudulent liquor manufacturers, who dilute the liquor with water, although there are some who would not like to believe it, but it is true that when you balance with the scales, there is a pound of liquor, a pound of water in a bottle of liquor." So, the history of human development is accompanyed by the history of food fraud as well.

Firstly, food fraud brings potential adverse health hazards to consumers. Food is the most basic material of human life. In comparison with other types of product fraud, food fraud has high sensitivity as it may cause varying degrees of harm. These incidents may lead to public health or population-wide emergencies and can also cause social unrest issues (e.g., lowering consumer confidence in the food supply and the government). In general, the vast majority of food fraud does not cause a public health hazard, but due to uncertainty about how the fraudsters handle the products, it may lead to a large-scale hazard event [7–9]. For example, according to a report by the former Ministry of Health (MOH), the 2008 melamine-tainted infant formula incident in China caused 294 000 infants and young children to be diagnosed with urinary tract stones, and 6 deaths [10, 11].

Secondly, food fraud causes consumers to suffer economic losses when they thought they had bought high-priced products such as Chinese caterpillar fungus, and *colla corii asini* (donkey hide gelatin), but instead received fake low-priced products. Furthermore, food fraud can have negative consequences for food companies such as product recalls or loss of sales that dramatically reduce the value of domestic and exported Chinese food products [12].

In comparison with all other product frauds, the negative impact of food fraud is more extensive, since frequent food fraud incidents reduce public confidence in the authorities and the credibility of government agencies, and might even cause other social problems.

It has been stated in numerous reports and publications that food fraud is not usually a health "risk" but always creates "vulnerability." The unique health danger of food fraud is that the criminal actions are unknown and usually novel, so traditional food safety and public health systems and countermeasures do not catch or prevent food fraud. For example, in the United Kingdom (UK) horsemeat was illegally added to beef to reduce the cost of the product. Horsemeat had a lower price than beef so adding even small amounts of horsemeat significantly reduced the cost of goods for the fraudster supplier. Testing determined that there was no health "hazard" or "risk" associated with the horsemeat issue. But there was "vulnerability" because the manufacturing process for horsemeat was not reviewed or monitored. If there had been a health hazard associated with the fraudulent horsemeat, the usual recall and traceability systems would not work as no one would have known there was horsemeat in the beef.

Food fraud can be divided into the following seven categories [12]: (i) adulterant substance: a component of the finished product is fraudulent (e.g., melamine added to milk),

(ii) tamper: legitimate product and packaging are used in a fraudulent way (e.g., changed expiry information, product up-labeling, etc.), (iii) over-run: legitimate product is made in excess of production agreements (e.g., under-reporting of production), (iv) theft: legitimate product is stolen and passed off as legitimately procured (e.g., stolen products are co-mingled with legitimate products), (v) diversion: the sale or distribution of legitimate products outside of intended markets (e.g., relief food redirected to markets where aid is not required), (vi) simulation: illegitimate product is designed to look like but not exactly copy the legitimate product (e.g., "knock-offs" of popular foods not produced with the same food safety assurances), and (vii) counterfeiting: intellectual property rights infringement, which could include all aspects of the fraudulent product and packaging being fully replicated (e.g., copies of popular foods not produced with the same food safety assurances). All types of food fraud can lead to a lack of consumer trust in the food supply chain, but the most concerning types are adulterant substances followed by counterfeiting.

China has a unique place in the global supply chain of foods. It is both an importer of foods for domestic consumption and a growing exporter of food products. As the quantity, quality, and varieties of Chinese food increases, issues of domestic food production and imported foods will become more complex, which will increase the negative consequences of food frauds.

16.2 Overview of Food Fraud in China

The rapidly growing Chinese economy has led to a gradual change in focus from food security to food safety. The related reports on food safety also show a significant increasing impact [13, 14]. According to a report by the General Administration of Quality Supervision, Inspection and Quarantine of China (AQSIQ), the media reported that 266 of 694 typical food safety incidents from 2007 to 2013 were non-food adulterant substances, and 128 of them were tampering [15]. This report indicated that problems with meat, dairy products, oil, vegetables, and drinks led food fraud events. Similarly, more than half of the nearly 4000 records from 2004 to 2015 in the food scandal database "Throw It Out of the Window" (a non-governmental website in China) were food fraud [16, 17]. Thus, due to this heightened consumer awareness, food fraud is the top issue for Chinese food safety legal and regulatory activities. below are some examples of typical food fraud incidents in China.

16.2.1 Fuyang Counterfeit Milk Powder Incident

Since 2003, over 100 unscrupulous enterprises and traders in Fuyang, Anhui province manufactured sub-standard milk powder [18]. They completely or partially replaced milk with inexpensive food ingredients, such as starch, sucrose, and flavorings. Thus, the essential protein, fat, vitamins, and minerals needed for infant growth and development were far below the legal, national standards in these products. Long-term consumption of such inferior milk powder can cause infant malnutrition, growth retardation, and decreased immunity, leading to a variety of diseases and even death. At least 12 babies died in this incident, while hundreds of babies suffered grievous bodily harm, but survived.

16.2.2 Melamine Milk Powder Incident

Melamine is a synthetic chemical that was added to raw milk to increase the apparent protein content [10]. In September of 2008, Sanlu brand milk powder was found to cause an outbreak of kidney disease, due to the baby formula being contaminated by melamine. According to the former MOH, dated December of 2008, six babies died and 294 000 were hospitalized by consuming the tainted formula [11]. Melamine was also found in dairy products produced by other dairy companies including Mengniu, Yili, and other milk producers [19]. Additionally, melamine was found in feed, eggs, candy, and other dairy commodities. This scandal has seriously affected the reputation of the Chinese food industry and caused a dramatic decrease in exported dairy products and domestic consumer confidence.

16.2.3 Gutter Oil Incident

Gutter oil is a term used in China to describe illicit cooking oil that has already been used and is then processed by cleaning and filtering, or animal oil derived from illegal animal fats. The criminals usually blend some small amount of gutter oil with the normal edible oil to lower the cost of goods and increase the profits. Gutter oil is also presented and sold as genuine, inexpensive normal cooking oil. The sources of this oil are thought to be from leftover or used oil from restaurant fryers, oil extracted from discarded animal parts, animal fat, internal organs, and expired or otherwise low-quality meat.

In the past decade, gutter oil incidents have been discovered in provinces including Chongqing, Guangdong, Hubei, Hebei, Shandong, Jiangsu, and Shanghai [20]. In July 2010, The State Council announced a pilot study on the prevalence of illegal gutter oil and other kitchen waste. In 2012, Chinese police disbanded a nationwide gutter oil criminal group worth up to 10 million dollars, involving 117 large and medium food enterprises and individual food grain stores in 14 provinces [21]. In 2014, Chang Guann Co. Ltd. – a well-known enterprise in Taiwan – was found selling tainted oil from fryers and cookers (the incident included more than 200 companies, including Wei Chuan Co. Ltd.), causing the contamination of hundreds of food products [22].

16.2.4 Functional Food Fraud

Functional food, also known as food with a health claim, is “A particular health care food claimed to have a health care function or for the purpose of supplementing vitamins and minerals, which is suitable for certain people to eat, and has the function of regulating the body, not for the purpose of treating diseases, and does not produce any acute, subacute or chronic harm to the human body,” according to The Functional Food Registration Management (New Law) issued on July 1, 2005. The ingredients and by-products of functional foods should not cause any harm to human health and should meet the China National Food Safety Standards and related regulations. Due to the specialty attributes and often higher prices, there is an increased fraud opportunity. There is a temptation for fraudsters to add adulterant substances that are illegal, poisonous, or should be taken by prescription only into a functional food in order to achieve its function claim. In July 2002, the former MOH rescinded the registration of 13 functional food products, eight of which contained undeclared prescription pharmaceutical ingredients, including fenfluramine, ephedrine, and furosemide, while four contained sildenafil [23]. In June of 2004, chemical drugs were detected in all of the 18 weight-loss products in a survey by the Shanghai FDA [24]. The Beijing FDA reported a weight-loss functional food containing sibutramine and phenolphthalein in February 2011 [25]. In the first half of 2015, the China FDA conducted two investigations of functional foods and analyzed a total of 1854 products; 14 contained sildenafil and other prohibited ingredients, while 5 were counterfeit products [26].

Many other typical Chinese food fraud incidents can be found in reference 27, many of which have been reported widely within China, which has raised consumer awareness and concerns, and lowered consumer confidence in the domestic food supply chain.

16.3 Influential Factors and Characteristics of Food Fraud in China

China has many unique and very challenging market logistics and consumption patterns that increase the complexity and challenge of preventing food fraud due to its unique types of food and cooking processes that differ from the rest of the world. While the exact types of food fraud may be unique, there are universal underlying principles of food fraud prevention that can be used.

16.3.1 Food Authenticity

Different products, markets, and consumption patterns have different fraud opportunities. In developing countries there is more consumer interest in food safety threats. Consumers pay attention to the authenticity of food, such as the country of origin [28]. In order to earn more profits, producers or traders up-label the product or intentionally make a false or misleading statement about the food. The product may not have a human health hazard because of this, but without being able to confirm that good manufacturing practices were followed – including traceability – there is vulnerability for future hazards. During 2011–2012, the EU Rapid Alert System for Food and Feed (RASFF) reported 118 notifications of "Adulteration/Fraud." Only four were for fraud such as adulterant substances or counterfeits, while the others were mainly illegal imports, or missing or improper product certificates [29]. While there is an ever increasing interest in premium and value-added products, China is more concentrated on food safety due to the vulnerabilities for health hazards from adulterant substances. Uncertain adulterant substances, some of which are harmful or toxic, are a significant and immediate threat to the health of consumers.

16.3.2 The Complex Chinese Food Chain

Food fraud incidents are not new in developed markets. About a century ago, food fraud from the adulterant substance diethylene glycol (DEG) was one of main reasons for the implementation of the very first USA food laws in 1906 and 1938. Unfortunately, DEG problems still exist and it is one of the reasons for the 2009 US FDA public meeting on EMA. Generally, with the rapid development of the food and chemical industries, the use of new materials, and booming global trade, food fraud – especially adulterant substances – has become a global issue. Due to globalization, more products are moving faster and farther around the world. Each region has its unique and complex characteristics. Due to massive growth and changing markets, China's food fraud prevention is more complex, complicated, and challenging in comparison with other developed markets, such as Europe and the USA. In the past three decades, China has shifted from an agricultural to an industrial economy, along with rapid economic growth. Some of China's regional development has been slow to increase in capacity and adopt new technology. According to statistics, small-scale and scattered food producers with no more than 10 employees now account for 80% of the total 448 000 Chinese food producers. Food production companies who are small scale, scattered, and poorly organized account for 75% of the entire food production enterprises [30]. For these small producers, there is sometimes a lack of education or awareness of good manufacturing practices or even of basic food safety hazards. This local complex and interwoven supply chain, including a lack of transparency and supervision, leads to food safety and food fraud vulnerabilities [31].

16.3.3 Urbanization

The urbanization in China is the largest human migration in history. There are many economic benefits of urbanization and they coincide with tremendous logistical challenges and changes, including getting enough safe food to the city centers. The longer and higher-velocity food supply chains, combined with new market participants, will continue to create tremendous growth, but will also create new food safety and food fraud risks. Managing food safety and food fraud will be critical to meeting the needs of the migrating residents, which will support the continued growth of the Chinese economy. Food safety and food fraud has been a critical component of the "five-year plan" systems, both in the past and the present.

In the past, food fraud usually occurred more in rural areas outside the more formal food supply chains and beyond the oversight of the agencies [32]. For example, victims of fake milk powder were mostly rural babies. Rural food safety is now a top concern for China. In comparison with urban settings, the rural markets are more scattered, and less regulated, include low-cost illegal schemes, and there is often more local protectionism. In addition, the education level of rural consumers is relatively low, resulting in less awareness of food quality and food safety, as well as the knowledge of or the ability to distinguish food fraud. Rural household incomes are usually lower than urban households, which leads rural consumers to seek less expense and potentially risky food products.

16.4 China's Management of Food Fraud

In contemporary China, the emergence and spread of food fraud not only causes health and economic losses, but is also an issue for social development, and is closely linked with the economic development level, policies and regulations, culture and environment, and so on. Thus, food fraud management and response is a systematic project involving multiple levels of legal, institutional, and technological coordination.

16.4.1 Legal Regulations

The outbreak of the melamine incident in 2008 accelerated the introduction of food safety regulations, which include provisions for "non-traditional" food risks such as food fraud. The implementation of the Food Safety Law of the People's Republic of China on 1 October 2009 was a milestone. It provided a legal basis for the further strengthening and improvement of China's food safety supervision. The law stated that China should build a food safety traceability system covering the whole food supply chain. This would prohibit the production and operation of any fraudulent, counterfeit, sub-standard food additives and food-related products. The law mandated that food and ingredient labels and instructions do not contain false information, and also may not include statements of disease prevention or treatment. The food producers or marketers are responsible for the contents of the labels and the specifications of the supplied products. The government encourages food production enterprises to be in line with good manufacturing practice requirements and implement food safety management systems, such as the Hazard Analysis and Critical Control Points (HACCP) plan.

On October 25, 2013, the Twelfth Session of the National People's Congress examined and adopted the newly revised Law of the People's Republic of China on Protection of Consumer Rights and Interests that became effective on 15 March 2014. The law increased the penalties on product frauds, increasing the cost of illegal businesses.

It is a significant statement that the Food Safety Law is supported by a "strict liability" under criminal law. The Criminal Law of the People's Republic of China Article 143 states that: "Whoever produces or sells food that is not up to hygiene standards, thus causing an accident of serious food poisoning or resulting in any serious disease caused by food-borne bacteria, shall be sentenced to fixed-term imprisonment of not more than three years or criminal detention and shall also, or shall only, be fined not less than half but not more than twice the amount of earnings from the sales; if serious harm is done to human health, he shall be sentenced to fixed-term imprisonment of not less than three years but not more than seven years and shall also be fined not less than half but not more than twice the amount of earnings from sales; if the consequences are especially serious, he shall be sentenced to fixed-term imprisonment of not less than seven years or life imprisonment, and shall also be fined not less than half but not more than twice the amount of earnings from sales or be sentenced to confiscation of property."

Then Article 144 states: "Whoever mixes the foods that he produces or sells with toxic or harmful non-food raw materials or knowingly sells such foods shall be sentenced to fixed-term imprisonment of not more than five years or criminal detention and shall also, or shall only, be fined not less than half but not more than two times the amount of earnings from sales; if an accident of serious food poisoning or any serious disease caused by food-borne bacteria has resulted, thus seriously harming human health, he shall be sentenced to fixed-term imprisonment of not less than five years but not more than 10 years and shall also be fined not less than half but not more than two times the amount of earnings from sales; if death is caused to another person or especially serious harm is done to human health, he shall be punished according to the provisions in Article 141 of this Law." The new Articles in the criminal law include the most severe food fraud penalties in the world. For serious cases of food fraud, the law allows extreme penalties including life imprisonment and the death penalty.

16.4.2 The Black List System

The main type of food fraud that is a concern for consumers, in part based rightly on human health hazards that have led to more public awareness, is the presence of illegal chemical adulterant substances. Globally, and in China, consumers are concerned by the unknowns of the adulterant substances as well as a personal feeling of violation and vulnerability. There is an expectation and demand that food be safe. Consumers are extremely prone to panic when food fraud incidents take place. The concern increases when there is a report of another major public health event due to the high toxicity of the adulterant substances. After the melamine incident in 2008, in order to curb fraud using non-edible substances and the abuse of food additives in food during the process of food production, distribution, and catering services, the Chinese National Commission of Food Safety in the State Council launched a food safety special rectification action to concentrate and crack down on the illegal addition of non-edible substances to food. The Chinese National Food Safety Clean-up and Rectification Office was established, which is supported by a panel including 133 experts and covering the field of risk assessment, food standards, food testing, food production, processing and operations, government laboratories, agriculture, including planting, breeding, and fishery, and others. During the three-month rectification process, many fraudulent behaviors were investigated and subjected to the relevent penalties. These occurred in areas such as research, manufacturing, marketing, and retailing. According to the requirement of the Office, the group published the first List of Non-Edible Substances that Might Adulterate Food and Easily Misused Food Additives (hereafter referred as "the Black List"). Initially, the Black List was the outcome of a recommendation by the expert panel. The process of creating this list included collecting options from the experts, government, and food agencies, discussion within the expert panel, a summary review by the former MOH, before it was issued by the Office.

The Implementation Regulation for the Food Safety Law of People's Republic of China (the first version in 2009) Article 49 states: "The MOH shall publish the list and test methods of non-food chemical substances and other substances possibly endangering human health that are added or possibly added to foods, according to disease information, information on supervision and management, and other factors. The AQSIQ, the State Administration for Industry and Commerce (SAIC) and the State FDA (now all merged into the China FDA) shall take the appropriate regulatory measures." This provision confirms the establishment of the Black List to combat food fraud. From December 2008 to June 2011, there were six batches of updates to the list. By June of 2011, there were 48 kinds of non-edible substances (64 chemical substances) and 22 categories of food additives on the Black List [33].

To crack down on adding illegal substances to functional food and to protect the health of consumers, the China FDA developed and issued a Black List for functional foods in 2012, covering 47 illegal substances in six categories of functional food [34].

These Black Lists of food products reflect the main food fraud regulatory focus. Both lists are significant and useful for food fraud prevention. While they do not cover all non-food substances illegally added to food products, they do provide clear cues and clues for combating food fraud activities. The lists also serve as a scientific basis for food safety risk supervision and evaluation. The judicial interpretation of the May 2013 Supreme People's Court's Law explicitly determines the substances included in these Black Lists to be "toxic and harmful non-food raw materials" [35]. After the promulgation of the Judicial Interpretation, progress has been made by the public security authorities, including police and other law enforcement agencies across China to combat food fraud crimes.

It is important to review that food fraud is very clearly addressed in Chinese criminal law in addition to food law or regulation. Many countries address food fraud or specific areas such as EMA, food integrity, or food authenticity under a regulatory system. A food fraud act may not explicitly be a violation of a criminal statute and may not be handled by the criminal courts or prosecutors. The identification of food fraud as a criminal statutory legal violation raises the level of scrutiny by agencies and the penalties for the criminals. Food fraud is explicitly defined as a violation of a criminal statute and the perpetrators are clearly criminals. The Chinese agencies use these criminal laws.

The China National Center for Food Safety Risk Assessment (CFSA), under the mandate of the National Health and Family Planning Commission (NHFPC), revised the list of non-food substances based on the Black List. If after determining that a substance is a non-food substance and falls outside the scope of relevant food safety laws and regulations, the focus is then placed on whether it is harmful to health, whether it qualifies as food fraud, and whether fraud will lead to serious consequences. In order to carry out the revision in a more scientific and comprehensive way, a special working group was formed, which was further divided into one expert group responsible for reviewing the Black Lists and another expert group responsible for reviewing the testing methods for these substances. Members of both groups were experts from government authorities in health, food and drugs, agriculture, grains, public security, import and export, quality, science and technology, education, and representatives from relevant food safety agencies and industry associations. The *ad hoc* working group established the criteria of inclusion and revision principles. The criteria of inclusion include:

1) The substance is a non-food substance;
2) The substance affects human health, has safety hazards, and poses a significant health risk to the human body;
3) The substance is used for the purpose of economic gain; and
4) The addition of the substance will have serious social disturbance and public security implications.

The principles of revision include:

1) Legal compliance;
2) Openness and transparency;
3) Safety; and
4) The avoidance of repetition of other laws and regulations.

In accordance with the criteria of inclusion and the principles of revision and on the basis of in-depth investigation, careful analysis, and thorough seminar discussion, the CFSA drafted a list of the non-food substances which, after being reviewed and approved by the *ad hoc* working group, was published on the official website of the NHFPC for the solicitation of opinions and suggestions from the public [36]. The new list, renamed as The List of Non-Edible Substances that Adulterate Foods, no longer includes food additives. The latter is now governed by the Chinese Food Safety Standards for General Principles of the Usage of Food Additives (GB 2760). The revised list of non-food substances has 23 categories of substance, including industrial colorants, nitrogen-rich substances, phthalic acid esters, and so on. It does not and cannot cover all non-food substances due to the many types of fraud. The list provides clues for food safety enforcers and sounds a warning signal to food producers and processors who try to commit food fraud. The items in the list are based on actual food fraud cases handled by the public security authorities, and food production and operation violations ascertained by food safety regulators. The list also provides relevant detection methods, noting that the methods should not be entirely relied upon and are for reference only. Whether a case constitutes illegal food fraud should be based on the actual food production and operation facts established by public security authorities and food safety regulators.

16.4.3 Food Fraud Detection System

In his book published in 1820, *Treatise on Adulteration of Food*, Friedrich Accum wrote about applying chemistry to detect food-adulterating substances. Today, the concept still applies, but we understand the need to be able to detect food fraud by selection of proper control systems or countermeasures. Chemistry remains an important means to combat food fraud activities. According to the properties of illegally added non-food substances and additives in food, there are many methods of detection, such as spectrophotometry, gas chromatography, gas chromatography-mass spectrometry, liquid chromatography, liquid chromatography-mass spectrometry, ion chromatography, capillary electrophoresis, and others [37]. At present, emerging detection methods such as enzyme-linked immunosorbent assay (ELISA), Raman spectroscopy, and biosensors are also increasingly used in combating food fraud due to their advantages in terms of rapid on-site detection. For the detection of fraud in functional foods that involves prohibited substances, liquid chromatography, and liquid chromatography-mass spectrometry are the main methods used. DNA technology is also frequently used in the detection of food fraud of meat products and aquatic products [38].

China has established a comparatively complete system for the detection of non-food substances in food. Detection methods are suggested for most of the listed substances, except for industrial and non-food-grade substances. The recommended detection methods provide effective supplementary means for addressing food fraud activities by providing a preliminary basis for determination of the presence of relevant substances in food. For non-food substances that occur naturally in food, such as thiocyanate and phthalocyanine green, the threshold levels are provided by combining their background levels determined through a large amount of sampling and the minimum levels of economically motivated adulteration. Despite many regulatory and enforcement efforts, China's food safety situation remains very serious. As the target substances of food fraud change, and the methods of fraud become more sophisticated and hidden, there is more and more need for the corresponding detection methods to be constantly enhanced and upgraded.

16.5 The Future of Combating Food Fraud

16.5.1 International Developments in Food Fraud Prevention and China's Strategy

While China has made significant progress in improving food safety, the situation allows for cautious optimism because food fraud issues are becoming increasingly complicated. The successful management of new laws and effective enforcement may reduce large-scale incidents. Although the fraud opportunities may be reduced, food fraud cannot be completely eliminated.

Internationally, the concept of a “food safety management system” has assumed wider dimensions that have expanded from traditional control of toxic and harmful substances in food to total food protection. This includes: terrorism, the use of illegal additives, illegal labeling, control of inferior-quality products disguised as good-quality products, and food fraud. The concept of a food safety management system is efficient because it focuses on prevention. There is an efficiency in coordinating countermeasures across the continuum of food quality, food safety, food fraud, and food defense. These risks are distinguished as the concepts of intentional or unintentional acts, as well as the motivations of economic gain or harm [1, 12]. This broader focus has given rise to a new food risk matrix (Figure 16.1) [1]. Looking forward, response to food fraud will be reliant on the combination of different technologies and means, such as the establishment of a traceability and pre-warning technology system and food fraud databases, food chain vulnerability assessment, and analysis and detection capability building.

16.5.2 Vulnerability Assessment of the Food Chain for Food Fraud Prevention

As the food supply chain becomes increasingly complicated, maintaining the authenticity and safety of food ingredients along the entire supply chain has become more important in ensuring that brands and consumers are not affected by food fraud. Measures that can be taken in response include: (i) conduct full-industry chain vulnerability assessment and develop key technologies for control of illegal food additives and trace food ingredients; (ii) shift the food regulatory paradigm from passive response to proactive prevention by establishing a constantly updated national food fraud database with automatic information collection; and (iii) strengthen food fraud identification and prevention capabilities to provide effective support for reducing the occurrence of food fraud and the losses caused to consumers and society. To characterize the vulnerability

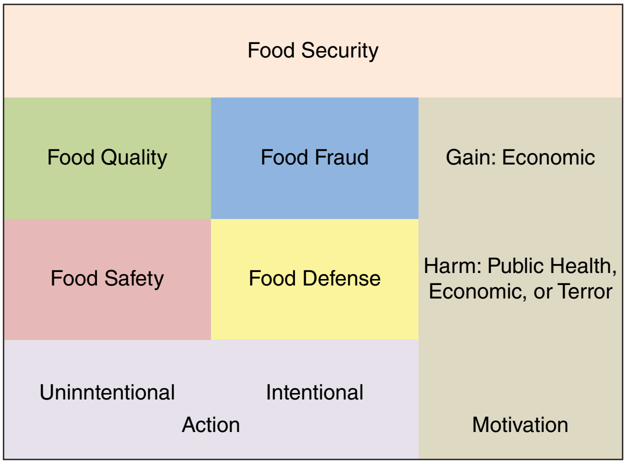


Figure 16.1 Food risk matrix.

of food fraud, the following three aspects must be assessed in the Food Chemical Codex [40]:

1) Vulnerability driven by factors inherent to the ingredient. Factors such as the ingredient market price, its fraud history, composition, physical state, and level of processing are entirely independent of the actions taken by the buyer to mitigate the risk of fraud. This is defined as the inherent vulnerability of a food fraud ingredient. Certain ingredients are by nature more vulnerable to adulteration (e.g., apple juices or apple purees are more vulnerable than apple pieces). Fraud history (past cases of adulteration of specific raw materials) is a good source of information. It is an indicator of the raw materials' potential vulnerability, and an important source of possible adulterants for which detection and deterrence are needed.
2) Vulnerability driven by factors impacting the business (business pressure). Factors such as the demand for a specific ingredient (volume), the extent of its use (ingredient used in several products and businesses), or the market price fluctuation may contribute to an increased level of vulnerability to fraud. Any anomaly in the economics of particular raw material sources is an indicator of raw material potential vulnerability. Drastic increases in market price and sources of raw material (e.g., poor harvest following bad weather, or causes by a new hazard) are good indicators of increased raw material vulnerability based on economic anomalies. Geopolitical considerations are also important to characterize vulnerability to food fraud. A country-specific low price compared with the rest of the market may indicate a lack of food control and/or regulatory/enforcement framework in a country through which the ingredient may transit.
3) Vulnerability driven by factors under the control of the buyer. This reflects the strength, or the weakness of a company's mitigation strategy (full traceability, adequate purchasing specifications, availability of analytical methods, robustness of surveillance programs).

In summary, assessing the risk of fraud for a food ingredient requires an understanding of the inherent raw material vulnerabilities, and the existing controls in place. This will allow definition of which preventive actions are needed (and where) to mitigate the risk of food adulteration.

16.5.3 Detection Technology Buildup

As food fraud becomes more sophisticated, it is critical for detection methods to be enhanced and upgraded correspondingly. Rapid detection devices have become effective means of speedy customs clearance of food and on-site food safety enforcement. Such detection devices based on antibody libraries and immunological techniques will be increasingly indispensable to internal inspections at food producers and regulatory inspections. Other means include the use of gas chromatography-mass spectrometry, especially high resolution mass spectrometry, to create multiple target screening databases for non-directional screening of illegal additives. The use of molecular biology, stable isotope, near-infrared, Raman spectrometry, and nuclear magnetic resonance technologies to develop endogenous characteristic-based food authenticity testing methods and food authenticity tracing-oriented databases of isotopes, molecular fingerprints, and genes for rapid screening for food fraud and to test food authenticity are available as well.

16.5.4 Establishment of a System-Wide Traceability and Early Warning System

It is important to establish a food safety system-wide traceability and early warning system. It should be based on public alerts and information from other agencies such as the AQSIQ, the China FDA, the CFSA, illegal additives data from academic research and scholarly journals, insight from international databases, and food safety enforcement investigations. Other measures include the development of the system empowered by authenticity-tracing technologies, such as isotope fractionation databases, DNA barcodes, electronic codes and electronic labeling, formulating generic technical standards of food safety data collection and communication, integrating and analyzing food safety big data, such as food raw material databases and food safety information sources, and developing a food safety risk pre-warning and tracing platform. These measures will help to substantially detect and deter food fraud and improve food safety and authenticity.

16.5.5 Establishment of a Credit System for Food Based on Strengthened Regulation and Publicity

Since food fraud stems from intentional acts by humans, it is very difficult to solve them by solely relying on technical means, as it is impractical to test all food items. Dr. Spink has been quoted as stating, “If the biological organism in question was a microbe, we would use the discipline of microbiology; for food fraud the biological organism in question is a human so we should use the discipline of social science and specifically criminology.” Also, there are many types of food fraud incidents that do not include an adulterant substance, such as stolen goods. The complexity of food fraud incidents is the main reason behind China’s food safety supervision and the aggravation of the consumer trust crisis. More attention should be paid to the human factor by strengthening publicity and training, increasing food safety awareness of food professionals and stepping up food safety enforcement. This works to reduce the fraud opportunity, focuses on prevention, and reduces the likelihood of food fraud incidents in the first place. It is equally important to simultaneously increase consumer awareness of food safety.

The establishment of a certificate system in the food industry is a long-term mechanism and fundamental solution to food safety. In fact, as early as in the Song Dynasty of China, there was a mechanism of industry self-regulation that held industry associations accountable for the quality of products. According to an ancient work called *Ducheng Jisheng* (*Record of the Splendors of the Capital City*), “Industry associations are mandatory institutions found in all industries regardless of size or status, even including the trades of medicine and divination.”

In order to speed up the construction of a food industry enterprise certificate system, improve food producers’ safety management, and promote the food industry’s sustainable development, the Ministry of Industry and Information Technology formulated the Implementation Scheme of the Food Industry Enterprise Credit System [39]. This enforces benchmarking, compliance, and implementation of the system at food producers. It includes guidelines for the certificate management system implementation in key segments of the food industry. It also makes efforts to strengthen publicity and training on the industry certificate management standards and constantly improve the standards. It also works to strengthen local and industry certificate information platform networks, and promote publicity and exchange regarding the industry certificate management system. Meanwhile, it formulated the general requirements for food industry enterprises to establish and implement credit management systems (QB/T4111-2010) and provides instruction on the establishment and operation of the system in more than 5000 food industry enterprises. The Ministry of Science and Technology of China have also created a certificate alliance for a third-party food safety detection agency in September 2015. Relevant efforts will be further strengthened in the future and a full-featured social certificate system will eventually be established.

The China FDA released the Provisions on the Administration of the "Black List" System for Food and Drug Safety on December 12, 2013. This was done to further strengthen the supervision and management of food and drug safety, to promote the certificate system construction, and supervise the performance and duties of food producers and operators. Information to be published in the Black List includes the following: name, address, and legal representative of the violating producer/operator, main violations, basis of punishment, and results of punishment, and name, title and ID card number of perpetrator, main violations, basis of punishment and results of punishment; period of time for which violating producer/operator/perpetrator is banned from engagement in relevant activities; and product information, such as product name, batch number, labels, approval number, and production license number. The draft document also states that food and drug administration authorities at county level and above shall, in accordance with the Provisions, establish food and drug safety Black Lists which will be included in the China FDA's database for sharing of relevant information. There are also provisions for the publication of relevant information about punished producers/operators/perpetrators on government websites, public supervision, and aggravated punishment of repeated offenders.

16.5.6 Interdepartmental and International Cooperation

While there are many types of food fraud, adulteration is among the most consequential and harmful to public health and economic development. Adulterant substances are more likely to raise food safety and public health concerns in comparison with other kinds of food fraud in present day China. This is similar to food fraud incidents in the US, the EU, Great Britain, and Japan.

Food fraud has been treated as a public health and food safety issue in many countries around the world. For example, in the 2008 melamine-tainted milk powder incident, Chinese authorities and relevant organizations, including the food safety authority, public health authority, public security authority, medical organizations, food safety testing agencies, and producers, worked together to reduce the impact on consumer health and social disturbance, while maintaining government creditability.

Since food fraud is not limited to China and is a global issue, it is of particular importance to strengthen communication and exchange through a public–private partnership that includes interactions with other governments, non-governmental organizations, academics, industry associations, and individual companies. This collaboration could include the sharing of food fraud databases, technologies, and research and development cooperation. For example, China can have in depth cooperation with the Food Ingredients Expert Committee of the US Pharmacopeia Convention for vulnerability assessment as part of the formulation of the Food Chemicals Codex and the Vulnerability Analysis Critical Control Point assessments. With a coordinated effort to reduce food fraud opportunities, China can strengthen cooperation with the EU in food transparency technology. This can include taking part in the Horizon 2020 program and opening key food safety technology projects in China's key research and development programs in the 13th Five Year Plan period for 2016 to 2020, with the focus on food fraud vulnerability assessment, and food authenticity and traceability technology research, in a concerted effort to find solutions to food fraud. In 2015, China achieved recognized equivalency with the industry-led Global Food Safety Initiative (GFSI) food safety management system. GFSI has been leading many international activities, including defining food fraud, developing vulnerability assessments, and beginning the sharing of best practices for food fraud prevention. The CFSA has been involved with many international activities, which include research projects funded by the Chinese State Administration of Foreign Experts Agency (SAFEA). One project was between the CFSA and the Food Fraud Initiative at Michigan State University.

16.6 Conclusion

After decades of rapid economic development since China's reform and opening up in the late 1970s, food security against hunger is no longer an issue for the Chinese people. However, in recent years there has been a rise in food safety incidents and food fraud has become an increasing concern for the public and the government. Food fraud constantly evolves along with economic development, and has been a particular challenge to food safety. With the introduction of a full range of legislative and administrative measures, including the Food Safety Law, the Judicial Interpretation and the Black List mechanism, China has made significant progress in combating and reducing food fraud. China's overall food safety situation has been steadily changing for the better. Nevertheless, food safety vulnerabilities from food fraud remain a serious problem. The combination of a series of positive factors, such as the implementation of the Food Safety Law, increasing food safety awareness of producers, operators, and consumers, and the establishment of a social certificate system, will help to reduce the occurrence of food fraud incidents in China. However, like many countries in the world, China still needs to make continuous efforts to reduce food fraud, and protect food safety and consumers' rights and interests.

Acknowledgements

This study was supported by High-Level Talents and Experts Introducing Program for "Project 523" of the China National Center for Food Safety and Risk Assessment (1311613106702).

References

1 Spink, J. and Moyer, D.C. (2011) Defining the public health threat of Food Fraud. *Journal of Food Science*, 76(9), R157–R163.
2 Spink, J., Moyer, D.C., Park, H., *et al.* (2013) Defining the types of counterfeiters, counterfeiting, and offender organization. *Crime Science*, 2(1), 1–10.

3 Wilson, B. (2008) *Swindled: The Dark History of Food Fraud, from Poisoned Candy to Counterfeit Coffee*. Princeton University Press, Princeton (NJ, USA).

4 Shears, P. (2010) Food fraud: A current issue but an old problem. *British Food Journal*, 112(2), 198–213.

5 Lauer, B.H. (1993) The rage for cheapness: food adulteration in the United States, Canada and in the Dominion, 1850–1920. Master's Thesis, Carleton University, Ottawa, Canada.

6 Lotta, F. and Bogue, J. (2015) Defining food fraud in the modern supply chain. *European Food and Feed Law Review*, 10, 114–122.

7 Everstine, K., Spink, J., Kennedy, S. (2013) Economically motivated adulteration (EMA) of food: common characteristics of EMA incidents. *Journal of Food Protection*, 4, 723–735.

8 Moore, J.C., Spink, J., and Lipp, M. (2012) Development and application of a database of food ingredient fraud and economically motivated adulteration from 1980 to 2010. *Journal of Food Science*, 77(4), R118–R126.

9 Wheatley, V. and Spink, J. (2013) Defining the public health threat of dietary supplement fraud. *Comprehensive Reviews in Food Science and Food Safety*, 12, 599–613.

10 Wu, Y.N., Zhao, Y.F., Li, J.G., *et al.* (2009) A survey on occurrence of melamine and its analogues in tainted infant formula in China. *Biomedical and Environmental Sciences*, 22(2), 95–99.

11 The Ministry of Health of the People's Republic of China (2008) *The Medical Treatment Work in the Melamine Milk Powder Incident*, http://www.moh.gov.cn/mohbgt/s3582/200812/38386.shtml (accessed April 2015) [in Chinese].

12 Spink, J., Moyer, D.C., Park, H., *et al.* (2015) Introducing food fraud including translation and interpretation to Russian, Korean, and Chinese languages. *Food Chemistry*, 189, 102–107.

13 Lin, Y.Y., Zeng, H., Li, G.C., *et al.* (2009) Economic development is ultimate determinant of food safety: A case study of China. *Environmental Pollution*, 158(5), 1185–1188.

14 Wu, Y.N., Chen, Y. (2013) Food safety in China. *Journal of Epidemiology Community Health*, 67, 478–479.

15 China National Institute of Standardization (2015) The Summary Report of a National Science and Technology Support Program "The Research and Demonstration of Food Safety Hazard Information Collection and Early Warning Evaluation Model of Chemical Contamination (2012BAK17B01)", pp. 32–33 [in Chinese].

16 Wu, H. (2012) Throw It Out of the Window: *A Database of Reports on China Food Safety Problem*, http://www.zccw.info/index (accessed 4 April 2015) [in Chinese].

17 Wu, H. (2014) *The Case of Throws out the Window: Depth Observation of Food Safety in China*, The Economic Daily Press, Beijing [in Chinese].

18 Emergency Management Office of the State Council (2005) *Fuyang Counterfeit Milk Powder Incident*, http://www.gov.cn/yjgl/2005-08/09/content_21396.htm (accessed April 2015) [in Chinese].

19 The Ministry of Health of the People's Republic of China (2008) *Report for Press Conference on Melamine Milk Powder Incident: Infant Formula Sampling and Other Relevant Situation*, http://www.moh.gov.cn/mohbgt/s3582/200809/37917.shtml (accessed April 2015) [in Chinese].

20 The Ministry of Public Security of the People's Republic of China (2011) *Report on Gutter Oil Incidents*, http://www.mps.gov.cn/n16/n983040/n2868387/n2868447/3061731.html (accessed April 2015) [in Chinese].

21 The Ministry of Public Security of the People's Republic of China (2011) *Gutter Oil: From Black Market to Dining Table*, http://www.mps.gov.cn/n16/n1237/n1342/n803715/2906562.html (accessed April 2015) [in Chinese].

22 Xinhua News Agency (2014) *Gutter Oil Incidents in Taiwan*, http://www.xinhuanet.com/food/sp31/index.htm (accessed July 2015) [in Chinese].

23 Xinhua News Agency (2002) *The Ministry of Health Plans to Carry out Special Rectification on Functional Food*, http://news.xinhuanet.com/fortune/2002-07/30/content_504230.htm (accessed July 2015) [in Chinese].

24 Zhang, Y., Fan, R.L., Zhang, L.W. (2009) The problem of functional food safety in China and its countermeasures. *China Condiment*, 34(10), 29–31.

25 Jinghua Times News Agency (2012). *Beijing Food and Drug Administration: "Qiaomei" weight loss products are stopped selling*, http://news.xinhuanet.com/health/2011-02/15/c_121078270.htm (accessed November 2015) [in Chinese].

26 China Food and Drug Administration (2015) *Results of Food and Functional Food Product Quality Supervision and Inspection, April, 2015*, http://www.sda.gov.cn/WS01/CL1134/118620.html (accessed July 2015) [in Chinese]

27 Wu, Y., Miao, H., Shao, G., *et al.* (2016) *Food fraud in Food Safety in China: Past, Present, and Future* (eds Jen, J. and Chen, J. S.), China Science and Technology Press, Beijing, China, pp.172–192.

28 Tang, X.C., Li, X.M., Zhang, B.Y. (2015) Comparative research between domestic and abroad about Food Fraud. *Food Science*, 36 (15), 221–227 [in Chinese].

29 European Communities. (2013) *The Rapid Alert System forFood and Feed (RASFF) Annual Report 2012*. Office for Official Publications of the European Communities, Luxembourg.

30 Legal Daily News Agency (2014). *Small-scale and scattered producers are detrimental to food safety supervision in China*, http://www.cqn.com.cn/news/cjpd/983261.html (accessed November 2015) [in Chinese].

31 Clemons, E.K., Shao, J.C. (2012) Food tampering, fraud and "economic treason": The need for a new economic morality in China. *China Long March to Quality*, 3, 12–15.

32 Sheng, X.D. (2011) "Problematic food" designed for the rural market: Causes and countermeasures – analysis of corporate food fraud. *Enterprise Vitality*, 12, 59–62 [in Chinese].

33 National Health and Family Planning Commission of the People's Republic of China (2011) *List of Non-Edible Substances Might Be Illegally Added in Food*, http://www.moh.gov.cn/sps/s7892/201406/38e5c8a53615486888d93ed05ac9731a.shtml and http://www.nhfpc.gov.cn/sps/s7892/201406/3d82efba36ad4adea736a7a59c26f865.shtml (accessed December 2015) [in Chinese].

34 China Food and Drug Administration (2012) *List of Substances Might Be Illegally Added in Health Food*, http://www.sda.gov.cn/WS01/CL0847/69914.html (accessed December 2015) [in Chinese].

35 The Supreme Court (2013) *The Interpretation of Relative Law on Handling Criminal Cases Endangering Food Safety Issued by the Supreme Court and the Supreme Procuratorate*, http://www.court.gov.cn/fabu-xiangqing-5330.html (accessed December 2015). [in Chinese].

36 National Health and Family Planning Commission of the People's Republic of China (2014) *Solicitation of opinions and suggestions from the public on The List of the Non-Edible Substances Might Be Illegally Added in Food (draft)*, http://www.moh.gov.cn/sps/s5853/

201409/64a8d549311a432c8df6fb446fbfa8cc.shtml (accessed December 2015) [in Chinese].

37 Reid L.M., O'Donnell C.P., Downey G., *et al.* (2006) Recent technological advances for the determination of food authenticity. *Trends in Food Science and Technology*, 17, 344–353.

38 Zhang J., Zhang X., De D. L., *et al.* (2011) Review of the current application of fingerprinting allowing detection of food adulteration and fraud in China. *Food Control*, 22(8), 1126–1135.

39 Ministry of Industry and Information Technology of the People's Republic of China. (2014) *Implementation Scheme of the Food Industry Enterprise Credit System*, http://www.miit.gov.cn/n11293472/n11293832/n11293907/n11368223/16023418.html (accessed December 2015) [in Chinese].

40 US Pharmacopeia. Appendix XVII: Food Fraud Mitigation Guidance. *Food Chemicals Codex*, 10th edition, US Pharmacopeia Convention, Rockville, MD, USA. http://www.usp.org/sites/default/files/usp_pdf/EN/fcc/food-fraud-mitigation-guidance.pdf (accessed June 2016).

Part 4

Risk Assessment and Communication

17

Risk Assessment in China: Capacity Building and Practices

Ning Li and Zhaoping Liu

China National Center for Food Safety Risk Assessment, Beijing, China

17.1 Introduction

Risk assessment is a scientifically based process to characterize the potential hazards and the associated risks to a healthy life resulting from exposure to biological, chemical, or physical hazards in food [1]. It is an important scientific component in the risk analysis paradigm, which has been used to facilitate consistent and science-based decision-making in food safety. Risk assessment, as defined by the Codex

Alimentarius Commission (CAC), consists of four steps: (i) hazard identification, (ii) hazard characterization (including dose–response assessment), (iii) exposure assessment, and (iv) risk characterization [2].

At the international level, risk assessment of food chemicals is undertaken by two joint expert bodies: The Joint Food and Agriculture Organization of the United Nations (FAO)/World Health Organization (WHO) Expert Committee on Food Additives (JECFA) and the Joint FAO/WHO Meeting on Pesticide Residues (JMPR). Both the JECFA and the JMPR provide scientific advice to the CAC and its respective committees, who make the final decisions on how to control risk from food chemicals [1]. Over recent decades, many developed countries have applied risk assessment to the governmental decision-making process for food control systems. Following international principles and steps, they have developed new approaches and practical tools to update risk assessment methodology and make it more precise. For instance, the benchmark dose (BMD) approach was developed and applied to identify the point of departure for chemicals in dose–response assessment processes. The JECFA has used it to establish acceptable daily intakes, replacing the no-observed-adverse-effect-level (NOAEL) approach [3]. The US EPA has developed a cumulative risk assessment strategy and method for risk assessment of chemical mixtures [4].

Risk assessment has also been preliminarily applied to food safety control in China for more than 30 years. In the 1980s, China set the maximum limits for cadmium, lead, and other contaminants in foods, based on health risk assessments to the Chinese population. Since 1995, China began total diet studies (TDS) following international guidelines [5].

Food Safety in China: Science, Technology, Management and Regulation, First Edition.
Edited by Joseph J. Jen and Junshi Chen.

In 2008, Chinese scientists carried out a risk assessment of melamine in infant formula and provided scientific results for setting its temporary level of action [6]. However, the Chinese government did not put in enough resources into the risk assessment workforce due to the absence of legal laws, which in turn, led to risk assessment failing to play an important role in food safety risk management. Since 2009, the Chinese risk assessment system has been developed in accordance with the Food Safety Law of the People's Republic of China.

17.2 Laws on Risk Assessment in China

In 2006, for the first time, China issued and implemented the Quality and Safety Law for Agricultural Products. In it, the risk analysis paradigm and the risk assessment concept were formally introduced to the food control system as legal regulations [7]. This law provides agro-product risk assessment regulations, especially focusing on veterinary drugs, pesticides, and other plant protection chemicals. The Food Safety Law of the People's Republic of China, issued in 2009 and revised in 2015, further focuses on the regulated development of the food safety risk assessment system in China [8]. Since then, the risk assessment system has been well designed and is developing quickly at the national level in China.

Based on the Food Safety Law, the National Health and Family Planning Commission (NHFPC) is the ministry in charge of food safety risk assessment at the central governmental level. The China National Expert Committee on Food Safety Risk Assessment is responsible for this task at the scientific level. Other food-related governmental agencies, such as the China State Food and Drug Administration, the Ministry of Agriculture, and the General Administration of Quality Supervision, Inspection, and Quarantine are tasked to assist the NHFPC by providing proposals on risk assessment and sharing scientific data and information as required. According to Article 17 in the new Food Safety Law, risk assessment should focus on biological, chemical, and physical agents present in food, food additives, and food-related products, including food-contacting materials. The Food Safety Law uses risk assessment as a science-based part of food safety management. For example, Article 17 of the law states that "Food safety risk assessment should use scientific methods on the basis of data and other information from food safety risk surveillance and monitoring." The law also defines the roles of risk assessment in risk management. It is described in Article 21 of the law that risk assessment results should serve as the scientific basis for developing food safety standards and selecting food safety control options [8].

The new Food Safety Law lists, in Article 18, five situations where there is a need to conduct risk assessments: (i) when a highly possible safety problem in food is revealed in risk surveillance or reported; (ii) when required for developing or revising food safety standards; (iii) to identify a priority list of safety supervision, control, and high-risk foods; (iv) to find new emerging risks; and (v) to determine whether a factor constitutes a food safety risk.

The NHFPC will make a decision on whether to carry out a risk assessment for each situation, after considering all the available information.

17.3 Risk Assessment Organizations in China

To implement a food safety risk assessment according to the law, the NHFPC established two scientific organizations in succession. First, the China National Expert Committee of Food Safety Risk Assessment was created in 2009. The committee consists of more than 40 qualified scientists nationwide, is responsible for the setting of an annual plan and proposing priorities for risk assessment. The committee is also tasked to conduct peer-reviews of risk assessment reports and risk communication for all stakeholders.

Second, the NHFPC set up the China National Center for Food Safety Risk Assessment (CFSA) in 2011. The CFSA is responsible for risk assessment and serves as the secretariat for the China National Expert Committee of Food Safety Risk Assessment. The center's mission is to provide technical support for China's food safety control system, including conducting risk assessment tasks and developing risk assessment approaches and databases. In 2013, the CFSA developed an NHFPC Key Laboratory for Food Safety Risk Assessment, which has been engaged in research and development of advanced technologies and methodologies for food safety risk assessment. In short, the Chinese national scientific network of food safety risk assessment is now composed of the National Expert Committee, the CFSA and the NHFPC Key Laboratory for Food Safety Risk Assessment.

17.4 Capacity Building for Risk Assessment

After the implementation of the Food Safety Law in 2009, China has developed its food safety risk assessment system and carried out capacity building in risk assessment. Since 2010, the National Expert Committee of Food Safety Risk Assessment has developed and published a series of guidance documents for risk assessment, including technical guidance for conducting food safety risk assessments and requirements for data collection in risk assessment. These documents follow international guidelines and serve as scientific references for Chinese scientists when they conduct risk assessment work. Working together with the National Expert Committee on Food Safety Risk Assessment, the CFSA developed effective working procedures and operational mechanisms for food safety risk assessment. The main steps involved are included in this procedure, such as the proposing of risk assessment projects, setting up top priorities, conducting the risk assessment work, and reviewing and submitting of the technical reports.

To meet risk assessment requirements, the CFSA has been focused mainly on the development of risk assessment methodologies. A long-term food consumption model and a large portion dietary exposure model have been developed and applied to risk assessment over the past three years. The NHFPC Key Laboratory for Risk Assessment has carried out research on risk-assessment-related technologies and developed high-volume output detection methods. The Key Lab has also studied the toxicological effects of rare earth elements on rats, which provided an NOAEL and dose–response model for risk assessment of these chemicals present in Chinese teas. China has successfully conducted five total diet studies and developed advanced detection methods for persistent organic pollutants, including dioxins and perfluorinated compounds in blood and human milk.

Risk assessment is data dependent and the success of a risk assessment project will depend on, to a large extent, the quality and quantity of data available. Over the past six years, data collection and further database set-up has been an important part of the Chinese risk assessment system. In the annual national risk surveillance/monitoring programs, contamination data (around 300 chemical and microbiological hazards) have been collected from 30 categories of food and more than 10 million data points obtained. In addition, China has also carried out food-borne disease surveillance and set up a database containing more than one million related data points. Regarding food consumption data, the CFSA carried out a national survey focusing on processed food consumption to fill the data gap left by other Chinese national food consumption survey programs. For instance, the CFSA conducted a survey on beverage and alcohol consumption in 16 provinces and formed a database containing consumption information from more than 50,000 Chinese. In addition, a toxicity database of roughly 1000 food chemicals has also been established since 2012. All the available data play a very important role in risk assessment development.

17.5 Practices and Roles of Risk Assessment in China

When developing the food safety risk assessment system, the NHFPC, cooperating with the National Expert Committee for Risk Assessment and the CFSA, launched over 30 priority risk assessment projects and urgent risk assessment assignments to answer requests from the various Chinese food safety regulatory agencies. Full risk assessments of dietary cadmium, aluminum, lead, phalates, *trans* fatty acids, ethyl carbamate, thiocyanate, and *Salmonella* and *Campylobacter* spp. in chicken were completed following the international risk assessment steps. Additionally, the CFSA has conducted rapid risk assessments of emerging events such as the melamine adulteration in infant formula, the manganese migrating from stainless steel pots, and the plasticizers detected in alcoholic drinks. These practices provided a scientific basis for national food safety risk management and international food trade dispute negotiation.

17.5.1 Promoting Revision of Standards for Food Additives Containing Aluminum

Since 2007, the national food safety risk monitoring system has found that more than 40% of food samples had aluminum (Al) concentrations exceeding the legal limit. These included food from 11 categories of food additives containing Al, such as steamed bread, noodles, and jellyfish, which are all very popular in China. Risk managers and consumers were concerned about the potential harmful health impact resulting from excess Al in foods and the appropriateness of the use of these food additives. To address these issues, the NHFPC commissioned the CFSA to carry out a risk assessment on dietary exposure to Al among the Chinese population.

This risk assessment found that residents in northern China and children less than 14 years of age had an average dietary intake exceeding the provisional tolerable weekly intake (PTWI) level for Al (2 mg/kg body weight/week) established by the JECFA in

2011. In all, 32.5% of the Chinese population had a higher Al intake than the PTWI and posted health risks. Among the food categories, steamed bread, noodles, fried dough sticks, and other wheat flour products were the major sources of dietary Al intake. Puffed food, on the other hand, contributed to a relatively high Al intake for school-age children.

In light of the risk assessment results and recommendations, the NHFPC ordered a review of the food safety standards for food additives containing Al. Releasing the Notice on Adjusting the Regulation on Using Food Additives Containing Al, the NHFPC required that, by 1 July 2014, sodium aluminum phosphate, sodium aluminum silicate, and starch containing aluminum octenyl succinate should not be used. Potassium aluminum sulfate and ammonium aluminum sulfate were banned from use in flour products such as steamed bread (except for fried flour products) and food additives containing Al were not permitted to be used in puffed food.

The NHFPC notified the China State Food and Drug Administration and the other regulatory agencies on these risk assessment results and further management opinions involving the control of Al intake. The commission suggested that relevant agencies should strengthen the monitoring and inspection of the use of Al in food and take a strong stance against the illegal use of food additives containing Al in food manufacturing processes. The CFSA experts interpreted food additives containing Al and the potential health impacts to the public based on the risk assessment results at an open day event. A full report on the risk assessment of dietary exposure to Al among the Chinese population is available online [9].

After the revision of the food additives standards, it is estimated that the level of Al intake will decrease by 84.4%–86.0% among residents of northern China and children less than 14 years to a level lower than the PTWI. It is expected that the health risk to the Chinese population due to Al intake will be lowered when the new Food Additives Containing Al Standard is in full compliance.

17.5.2 Providing Control of Plasticizers in Food

Since the plasticizer incident in Taiwan in 2011, phthalate esters (PAE), a type of plasticizer widely used in the food industry, have become one of the targeted chemicals in the Chinese food safety inspection system. As these compounds are widely present in the environment and can be detected in many food products, several governmental agencies have proposed the development of a plasticizer limit in foods as a risk management option. Upon a request from the NHFPC in 2012, the CFSA conducted a health risk assessment of PAE in the Chinese population, with a large-scale investigation of PAE contamination in 24 categories of food, including cereals, vegetables, meats, eggs, fish, milk products, vegetable oils, and liquors.

The results revealed that the average level of PAE in all major food categories was low (0.001–1.08 mg/kg). Dietary exposure to PAE was also significantly lower than the tolerable daily intake set by the European Food Safety Authority in 2005. There was no need for safety concern within the Chinese population [10]. In accordance with international principles for standards development, it was not rational and necessary to set PAE maximum limits in foods. On the basis of these risk assessment results, the Secretariat of the National Food Safety Standard Review Committee suspended the proposal for setting a PAE limit in foods, and recommended regulatory control measures to reduce plasticizer contamination of foods to improve food manufacturing processes.

17.5.3 Providing Evidence to Support the National Salt Iodization Policy

In recent years, the incidence of thyroid diseases, including thyroid tumors and nodules, has been on the rise. It is attributed, without scientific basis, to excessive iodine intake, especially by residents of China's coastal areas. Such opinion prompted the public and even some scientists to call into question the national universal salt iodization (USI) policy implemented in 1995. To review the impact of the USI policy on the elimination of iodine deficiency diseases and nutritional improvement of iodine, the National Expert Committee on Food Safety Risk Assessment carried out a risk assessment of the iodine status in the Chinese population twice, in 2010 and 2016.

Both risk assessments found that the Chinese USI policy had played a significant role in eliminating iodine deficiency diseases, including endemic goiter and endemic cretinism. Taking urine iodine concentration and dietary iodine intake considerations together, most Chinese residents, including in the coastal areas, had an appropriate iodine status and dietary iodine intake. This indicated that salt iodization did not cause excessive iodine intake in the Chinese population. However, in some regions with high iodine levels (300 μg/L or above) in the drinking water, residents would be at risk of excessive iodine intake if they consumed iodized salt. On the other hand, pregnant women, especially in regions with low iodine in drinking water, would at high risk of iodine deficiency if the iodized salt supply was removed [11].

These risk assessments not only provided evidence to support the Chinese USI policy in preventing iodine deficiency diseases, but also served as a scientific basis for continuously implementing USI policy with differentiating strategies in terms of iodine concentration in regional water resources.

17.5.4 Responding to Public Concern about *trans* Fatty Acids

At the end of 2010, several media reported on the safety issues of *trans* fatty acids (TFAs), with the misleading description of vegetable cream (cream made from hydrogenated vegetable oil) as "poison at the table." The unscientific stories caused a public panic about food containing TFAs, such as baked cookies and coffee creamer. Upon a request from the government, the CFSA collected data on TFA concentrations in major food categories and conducted a consumption survey focused on processed foods in Beijing and Guangzhou. A risk assessment study on the dietary intake of TFAs was completed in 2012.

The risk assessment research found that the energy contribution ratio of dietary TFA intake[1] in the Chinese population was 0.16%. In Beijing and Guangzhou, where processed foods were regularly consumed, the energy contribution ratio of TFAs was 0.4%, which is still far lower than the recommended limit of 1% by the WHO and significantly lower than the ratio in developed countries. Therefore, the dietary intake of TFAs in the Chinese population was not a risk. The risk assessment report suggested

---

[1] Energy contribution ratio of TFAs refers to the ratio of energy intake contributed by TFAs to total dietary energy intake.

that the public should reduce the intake of TFAs even though the current TFA intake does not pose a risk, as most research did not indicate that TFAs had a positive effect on health [12].

To promote better understanding of TFAs and their health risks, the CFSA published its risk assessment report online and communicated with stakeholders about the scientific information on TFAs through TV interviews, its official website, and Twitter. The risk assessment and subsequent active efforts made TFAs better understood by the media and public, with a scientific basis.

17.5.5 Reducing Disease Risk from *Salmonella* in Chicken

Food poisoning caused by non-typhoidal *Salmonella* (NTS) has been one of the most frequently reported food-borne diseases worldwide. Chinese national food safety risk surveillance in 2010–2012 revealed that, in China, 41.4% of chicken in retail was contaminated by NTS. Therefore, it was necessary to know the disease risk resulting from NTS in chicken.

In 2012, the CFSA carried out a risk assessment study of NTS in chicken, using a survey on NTS contamination in chicken and a test of cross-contamination in the home kitchens of six provinces. The risk assessment results showed that the chicken were more likely to be contaminated by NTS in cold storage than in freezing conditions. Five to eight million or more patients were estimated to be infected by NTS in chicken each year when considering other factors, such as cross-contamination in kitchens. In 50% of the cases associated with this, NTS contamination would be reduced in the chicken if good operating practices were followed properly.

The risk assessment report included key recommended steps for the prevention of NTS contamination in chicken, which would provide a scientific guide for reducing the disease risks resulting from *Salmonella* in chicken.

17.5.6 Providing a Scientific Basis for Tequila Import Restrictions

Tequila is a Mexican distilled liquor and has a high methanol content due to its raw materials being rich in pectin. According to the Mexican food regulations, the maximum limit for methanol in tequila is 3.0 g/liter (referred to as ethanol), which is higher than the limit set in Chinese distilled liquor (2.0 g/liter) specified by the Chinese Food Safety Standard (GB2757-2012). The difference in the maximum limit of methanol seriously restricted Mexican tequila export to the Chinese market. On request from the Mexican government, the NHFPC commissioned the CFSA to conduct a risk assessment study to evaluate the safety of the Mexican methanol limit (3.0 g/liter) in Mexican tequila when imported into China.

Risk assessment study results revealed that methanol intake from Mexican tequila would not exceed the safe intake level (20 mg/kg of body weight) developed by the International Program on Chemical Safety (IPCS), even if a person consumed 450 ml of Mexican tequila at one sitting. Considering the self-limiting nature of distilled liquor consumption, it was thus concluded that there was no increased acute or chronic health risk caused by methanol at 3.0 g/liter in Mexican tequila. Based on this rapid risk assessment report, the NHFPC issued a special administrative order to approve the import of Mexican tequila with a methanol content of 3.0 g/liter or below into China [13].

17.5.7 Presenting Evidence to Protect the Flour Industry against Adulteration with Borax

Borax and other borate compounds are non-edible substances that are included in the list of chemicals that cannot be legally used in food. In 2012, a study detected boron in a wheat flour product made by a well-known Chinese flour company. Several media outlets reported this information as an illegal use of borax in food.

Based on data from a baseline survey on boron content in food, the CFSA carried out an urgent risk assessment study. The results revealed that the naturally occurring concentration of boron in wheat flour could be up to 4 mg/kg and still would not cause adverse effects on public health under routine consumption conditions [14]. The boron concentration in the flour product reported by the media did not exceed the natural baseline of boron surveyed. This work provided evidence that the presence of boron in the flour product reported by the media was not the result of illegal adulteration and offered a scientific basis for judging the occurrence of boron in these flour products.

17.5.8 Proposing Control Points for Reducing Vibrio parahaemolyticus Contamination in Seafood

Food poisoning caused by *Vibrio parahaemolyticus* (VPH) is the most common foodborne disease in seafood consumed in China. Raw or under-cooked marine shellfish, such as oyster, are often contaminated by VPH and are considered to be a high-risk food. Thus, identifying the critical points to reduce or eliminate VPH contamination is important. The CFSA carried out quantitative surveillance on VPH contamination in ready-to-eat shellfish (e.g. oyster) in four Chinese provinces. A predictive microbiological investigation was also conducted for the whole food chain, mainly focusing on the transportation conditions and temperature of the shellfish.

The risk assessment study results showed that the contamination rate of VPH in oyster was high and consumption of raw oyster involves a high risk to health. The absence of a cold-chain system during transportation, a common practice in China's coastal areas, was found to be an important factor resulting in high VPH contamination. It was suggested that cold-chain transportation and storage was critical in reducing VPH contamination in seafood and should be integrated into the HACCP of seafood management operations.

17.5.9 Proposing an Action Level for Phthalates in Chinese Liquor

At the end of 2012, phthalates or plasticizers, especially DEHP and DBP[2], were detected in some Chinese distilled liquor. The public became concerned about the health risk of these plasticizers. The China AQSIQ had no idea as to how to supervise Chinese liquor containing plasticizer, nor about imported spirit products due to the absence of a referential level of risk management. On the request of the Food Safety Office of the State Council, the NHFPC commissioned the CFSA to conduct an urgent risk assessment study on DEHP and DBP in distilled liquor.

Based on the data collected in a survey of plasticizers in distilled liquor and other major foods, the CFSA assessed the health risk of DEHP and DBP, especially with regard

---

[2] DEHP: dinheptylortho-phthalate; DBP: dibutyl phthalate.

to adult drinkers. As a result, the dietary intake of DEHP and DBP from major foods and liquor was found not to be a risk. The distilled liquor contributed 57.3% DBP to the total dietary intake for adult drinkers. After calculating the worst-case scenario, it was concluded that DEHP and DBP levels would not cause adverse effects on the health of consumers if their concentrations in distilled liquor are lower than 5.0 and 1.0 mg/kg, respectively.

The NHFPC released these findings in this urgent risk assessment report and announced publicly that there is no safety concern if the concentrations of DEHP and DBP in distilled liquor are below 5.0 and 1.0 mg/kg, respectively [15]. To date, the China FDA and AQSIQ still use these values as their risk management of plasticizer levels in distilled liquor.

17.5.10 Investigating the Baseline Level of Thiocyanate in Milk

Being a chemical that causes thyroid function disruption, thiocyanate is on the prohibited list of chemicals in food. It therefore becomes one of the highlights in routine food supervision. However, thiocyanate is also a naturally occurring component in many foods, including dairy products. The China FDA needed scientific data to distinguish the natural presence of thiocyanate in dairy products from illegal adulterations.

From 2012, the CFSA collected approximately 2000 milk samples directly milked from the cow, in 12 Chinese provinces, the Netherlands, and New Zealand. Results of thiocyanate analysis showed that thiocyanate was detected in 66% of the collected samples. The average thiocyanate concentration was 2.2 mg/kg and the maximum level was 9.9 mg/kg. Based on these results, as well as considering economically motivated adulteration, 9 mg/kg was proposed to be a reference value for the baseline thiocyanate level in milk. A preliminary risk assessment found that, following normal dairy consumption, there was no health risk associated with thiocyanate lower than 9 mg/kg in liquid milk. The results have served as a scientific basis for the China FDA in distinguishing the natural occurrence of thiocyanate from adulteration.

17.5.11 Providing Scientific Information for Risk Communication

In February 2012, many media reported that, without any scientific background, manganese contained in some stainless steel pots exceeded the standard limit by as much as four times and would be harmful to human health. The public expressed concern about the safety of dietary manganese intake following the use of stainless steel cookware.

The CSFA collected stainless steel pots from supermarkets and studied the migration of manganese from the cookware to foods. The average migration of manganese into foods was found to be 0.35 mg/kg and when tested in the most extreme cooking conditions, it would lead to 1.05 mg/kg of manganese intake with an ordinary food consumption pattern. However, the normal daily intake of manganese from food and water, as a naturally occurring element, was about 7 mg. The total dietary intake of manganese was found to be lower than the upper level recommended by the Chinese Nutrition Society (10.0 mg per day). Therefore, manganese contained in stainless steel pots did not pose any health risk.

The CSFA held a press conference and officially released its risk assessment findings to the public [16]. Following the proper understanding of the relationship between manganese migration and health, the public panic caused by media report of excessive manganese in steel pots was eliminated.

17.5.12 Providing a Scientific Basis for Response to the Abnormal Levels of Mercury in Infant Formula

It was found in a national monitoring program that the concentration of total mercury in several infant formula samples was higher than the usual level in June 2012. The Food Safety Committee of the State Council requested that the NHFPC promptly commission the CSFA to conduct an urgent investigation and risk assessment of the total mercury levels in a wide range of infant formula products.

The survey found only one brand of infant formula produced by a famous company had abnormally high mercury levels, with a maximum concentration of 0.80 mg/kg. The risk assessment results showed that infant formula products with such high mercury concentrations would increase the health risk of infants if consumed over the long term. The rapid risk assessment provided a scientific basis for the official recall of this one brand of infant formula and other reasonable responses to this emergency, which revealed the important roles of monitoring and risk assessment in the food safety control system.

17.5.13 Assessing Risk of Eexposure to Aaflatoxins in Dairy Products

In December 2012, the AQSIQ found aflatoxin M1 in a few dairy products that exceeded its maximum limit. To provide sound support for a rapid response to this issue, the CSFA was requested to conduct a risk assessment study of the aflatoxin in dairy products.

According to the aflatoxin M1 contamination data collected in the national risk monitoring system in 2010–2011, it was estimated that the Chinese population had a low intake of aflatoxin M1 from dairy products. In the worst-case scenario, the probability of aflatoxin M1 from dairy products causing liver cancer was only 0.00168 case per million persons each year. Therefore, it was concluded that the health risk from aflatoxin M1 in dairy products was low. On the other hand, the aflatoxin M1 levels presented in dairy samples provided by the AQSIQ also posed a low risk if the product was consumed only in the short term. In order to decrease exposure to aflatoxin M1, the risk assessment report suggested prompt measures should be taken to completely withdraw dairy products contaminated by excessive aflatoxin M1 levels.

17.5.14 Responding to the Dicyandiamide-Tainted Milk Powder Issue

In January 2013, dicyandiamide (DCD) was detected in milk powder imported from New Zealand. Commissioned by the NHFPC, the CFSA quickly carried out a DCD survey in dairy products following the development of a DCD analysis method. The CFSA used data provided by New Zealand and assessed the potential risk of DCD to Chinese infants.

The results revealed that the maximum level of DCD detected in a milk powder sample was 2.4 mg/kg. The DCD intake from this sample in infants of different ages was 5% of the tolerable daily intake. There was no concern about the health risk caused by intake of DCD from the milk powder. The findings offered technical support for the

NHFPC to identify the risk level and the scope, and for other governmental agencies to take proper management actions.

17.6 Gaps and the Future

Over the last three decades, risk assessment approaches and methodologies have been developed and improved upon by international organizations and several governmental agencies in developed countries. China only started to apply this tool to food safety risk management after the implementation of the Food Safety Law promulgated in 2009. China has developed methodologies and databases required for food safety risk assessment over the past six years. However, there remains a gap between China and advanced countries in this field. The current capacity for risk assessment is not able to meet the practical demands of food safety in China.

The collaboration mechanism among various agencies on risk assessment that exists in advanced countries is still lacking in China. The joint effective risk assessment model is available at the international level as the JECFA and the JMPR under the charge of the WHO and the FAO. In most developed countries, multiple governmental departments contribute to risk assessment to enable risk assessors to have access to required resources and information. China does not have an integrated system and sufficient collaboration among governmental agencies in food safety risk assessment practice. Data sharing for risk assessment results among various government agencies in China needs further improvement. In addition, investment in risk assessment by the agencies in China is inadequate. The US and some European nations devote adequate financial and human resources to the field of risk assessment. This provides them with sufficient inputs to carry out risk assessment research and studies that ensure the improvement of the whole risk assessment system. Without adequate investment in the risk assessment field, China has technology gaps and a weak work capacity in comparison with advanced countries.

The Chinese food safety control system, having been reformed in 2013, demands strong scientific support from the risk assessment field. In the future, China should make stronger efforts to further develop and improve the food safety risk assessment system, in particular focusing on the development of new techniques unique to the social situation in China to close the gap with advanced countries.

To develop a nationwide network is important to carry out risk assessment in China. It is particularly important to develop a nationwide system at the central government level, which needs to adequately integrate the various governmental agencies into a central food safety risk assessment program. The NHFPC, the agency responsible for food safety risk assessment according to the China Food Safety Law, should develop an active mechanism to cooperatively work with other central government agencies. At the scientific level, additional experts from other ministries and related academic disciplines should be added to the Chinese National Expert Committee of Food Safety Risk Assessment. The academics, universities, and provincial centers for disease control and prevention should be incorporated, as technological resources, into a nationwide risk assessment network.

It is also critical to establish a central database of risk assessment data. The lack of adequate risk assessment data and related databases is a crucial constraint affecting risk assessment work in China. China should establish an inter-departmental mechanism for sharing data and pull all available data together to form a primary risk assessment database. In addition, a long-term plan for data collection should be proposed to meet future risk assessment demands. Toxicity testing and occurrence detection of food chemicals as well as food consumption survey data should be gathered and new research conducted to collect missing information and fill in data gaps. A sufficient database should be formed to serve as the basis for all food safety risk assessment needs in China.

Research and development in risk assessment is also an important aspect of capacity building in the risk assessment system. China should invest heavily in this field to strengthen the risk assessment system and to improve overall performance in this area. China has comparable performance regarding exposure assessments to other countries, but when it comes to hazard assessment, a substantial gap remains between China and advanced countries. Key approaches and techniques should be developed to identify and characterize new food hazards unique in China. The Chinese risk assessment organization should develop strong analyses for bio-monitoring and integrate its results into a dose–response assessment system. Physiologically based pharmacokinetic modeling and benchmark dose methods should be developed and used to derive health-based guidance values. Cumulative and quantitative risk assessment approaches, such as the application of food-borne illness and surveillance as a cost base of food safety outbreak outcomes, should be worked into the risk assessment capacity building system in China.

References

1 FAO/WHO. (2009) Environmental Health Criteria 240. Principles and Methods for the Risk Assessment of Chemicals in Food; WHO: Geneva, Switzerland.

2 FAO/WHO. (2008) Codex Alimentarius Commission Procedural Manual, 18th edn. Food and Agriculture Organization of the United Nations, Codex Alimentarius Commission (ftp://ftp.fao.org/codex/Publications/ProcManuals).

3 JECFA. (2011) Evaluation of certain contaminants in food. Seventy-Second Report of the Joint FAO/WHO Expert Committee on Food Additives. WHO Technical Report Series 959.

4 US EPA. (2003) Framework for Cumulative Risk Assessment. US EPA, Washington, DC, EPA/600/P-02/001F.

5 Junshi Chen, Junquan Gao and Xuqing Wang. (1994) China total diet study. *Newsletter of Medical Research*, 8:14–15 [in Chinese].

6 Yongning Wu and Yu Zhang. (2013) Analytical chemistry, toxicology, epidemiology and health impact assessment of melamine in infant formula: recent progress and developments. *Food Chemistry and Toxicology*, 56: 325–335.

7 The 10th Standing Committee of the National People's Congress of the People's Republic of China. (2006) Quality and Safety Law of Agricultural Products of the People's Republic of China. The 21st Session. Beijing [in Chinese].

8 The 11th Standing Committee of the National People's Congress of the People's Republic of China. (2009) Food Safety Law of the People's Republic of China. The 7th Session. Beijing. [in Chinese].

9 National Expert Committee of Food Safety Risk Assessment. (2014) Risk assessment of dietary exposure to aluminum in Chinese population. [in Chinese] http://www.cfsa.net.cn:8033/UpLoadFiles/news/upload/2014/2014-06/06495ded-eaba-4af8-82cc-f5318382a168.pdf (accessed November 2016).

10 Haixia Sui, Lei Zhang, Pinggu Wu, Yan Song, Ling Yong, Dajin Yang, Dingguo Jiang, Zhaoping Liu. (2014) Concentration of di(2-ethylhexyl) phthalate (DEHP) in foods and its dietary exposure in China. *International Journal of Hygiene and Environmental Health*, 217(6), 695–701.

11 National Expert Committee of Food Safety Risk Assessment. (2010) Salt iodination and risk assessment of iodine status in Chinese population. http://www.cfsa.net.cn/ewebeditor/uploadfile/20120316173037343.pdf (accessed November 2016) [in Chinese].

12 National Expert Committee of Food Safety Risk Assessment. (2012), Risk assessment of dietary intake of trans fatty acids in Chinese population http://www.cfsa.net.cn:8033/UpLoadFiles/news/upload/2013/2013-11/0ea2121b-1ac3-475a-b77c-e97342046b71.pdf (accessed November 2016) [in Chinese].

13 Pingping Zhou, Zhaoping Liu, Lei Zhang, Aidong Liu, Yan Song, Weifeng Mao, Ning Li. (2015) Preliminary risk assessment of methanol in tequila. *Chinese Journal of Food Hygiene*, 27(3), 99–102 [in Chinese].

14 Xiaoyu Song, Fengqin Li, Zhaoping Liu, Lei Zhang, Jianghui Zhu, Weixing Yan, NingLi, Junshi Chen. (2011) Boron background value survey of some food stuffs in 12 provinces of China and boron primary intake estimation of Chinese habitants. *Chinese Journal of Hygiene Research*, 40(4), 19–21 [in Chinese].

15 National Health and Family Planning Commission. (2014) Interpretation of risk assessment results of phalates in Chinese distilled liquor. http://www.nhfpc.gov.cn/sps/s3586/201406/db4c766638fd496a94907ddb267fcf73.shtml (accessed Novembe 2016) [in Chinese].

16 China National Center for Food Safety Risk Assessment. (2012) Manganese and health. http://www.cfsa.net.cn/Article/News.aspx?id=C3A3D689687AE8AAE134C92618FF8640948B90AAA101319E2B392ADFC8A5D500ADE75046E604CB2F (accessed November 2016) [in Chinese].

18

Microbiological Risk Assessment in Food

Xinan Jiao[1], *Jianghui Zhu*[2], *Jinlin Huang*[1] *and Qingli Dong*[3]

[1] *Yangzhou University, Yangzhou, China*
[2] *China National Center for Food Safety Risk Assessment, Beijing, China*
[3] *University of Shanghai for Science and Technology, China*

18.1 Overview of Microbiological Risk Assessment in Food

Microbiological risk assessment of food has always been a hot spot within international food safety research. Over the past 10 years, the Chinese Government has paid greater attention to food safety work and has strengthened the building of an effective risk analysis system. Since 2010, national food safety risk surveillance data have suggested that the number of reported food poisoning events caused by pathogenic microorganisms has been higher than the number of harmful events caused by toxic chemicals, animals and plants. Food safety risk caused by food-borne pathogenic bacteria is a global problem and the situation is more severe in developing countries. Thus, strengthening quantitative microbiological risk assessment to reduce the gap with developed countries is imperative from a national level. Since China has promulgated and implemented its "Food Safety Law" in 2009 and established the China National Center for Food Safety Risk Assessment in 2011, a lot of quantitative microbiological risk assessment studies aimed at domestic specific food-pathogenic bacterium combinations have been carried out.

18.1.1 Defining Food Microbiological Risk Assessment

Microbiological food safety issues are due to one or more events that affect population health, such as diarrheal disease, which can lead to hospitalization and death, caused by certain foods, pathogenic bacteriums, a processing course, region, transmission route or some composite factors [1]. Microbiological risk assessment (MRA) in food has been determined as an important field by the Codex Alimentarius Commission (CAC) [2, 3]. In the framework of the Codex, the most important objective of microbiological risk assessment is its use as a systemic analytical means to understand and deal with microbiological risk issues. In 1999, the CAC determined principles and guidelines for microbiological risk assessment work [3]. It is thus clear that microbiological risk assessment is still an emerging and developing science.

Food Safety in China: Science, Technology, Management and Regulation, First Edition.
Edited by Joseph J. Jen and Junshi Chen.

The Agreement on the Application of Sanitary and Phytosanitary Measures (SPS) by the World Trade Organization (WTO) has required that its member countries ensure these measures are based on risk assessment and are applied under appropriate conditions. The member countries should consider using risk assessment techniques established by relevant international organizations. The SPS Agreement has vigorously promoted the development of microbiological risk assessment and also supports concrete implementation of relevant standards, guidelines and suggestions in food safety. This provides a framework for modernization and uniformity of quarantine and plant quarantine measures. These measures must be built on a scientific basis and be fairly and transparently implemented. Unfair and non-transparent measures can't be implemented since they would be used as unjustified trade barriers discriminating against products provided by foreign countries or as means to give special preference to local products. In order to promote the production of safe food in domestic and foreign markets, the SPS Agreement encourages governments to develop national measures or use standards, guidelines and suggestions developed by international standard-developing institutes.

18.1.2 Developmental Processes of Domestic and Foreign Food Microbiological Risk Assessments

18.1.2.1 International

As early as 1998, an American regulator announced the first formal study result of quantitative microbial risk assessment (QMRA) in food: a risk assessment report of *Salmonella* Enteritidis in eggs [4]. In 2000, the US FDA (Food and Drug Administration) Center for Veterinary Medicine released a QMRA report about the impact of chicken meat contaminated by *Campylobacter* resistant to quinolones on the health of consumers [5]. In January 2001, the American Center for Food Safety and Applied Nutrition solicited public opinions on two microbiological risk assessment reports: the contamination of ready-to-eat food by *Listeria monocytogenes* [6] and the contamination of ready-to-eat raw oysters by *Vibrio parahaemolyticus* [7].

American experts have actively engaged in QMRA research with regard to international assessments. In 2002, the World Health Organization and the Food and Agriculture Organization of the United Nations released the first QMRA study result on *Salmonella* contamination in chicken and eggs [8]. Over the subsequent 13 years, 18 study results [9] were released widely involving *Salmonella*, *Listeria monocytogenes*, *Vibrio vulnificus*, *Vibrio cholerae* O1 and O139, *Enterobacter sakazakii*, *Campylobacter*, *Vibrio parahaemolyticus*, enterohemorrhagic *Escherichia coli*, parasites and many other pathogens. The studies also involved hazard identification, exposure assessment, risk rating and other key technologies in microbiological risk assessment.

In order to respond to the needs of the CAC, the FAO, and the WHO member countries – especially with the growing need for risk-based scientific ideas on microbiological food safety events – the FAO and the WHO created the JEMRA (The Joint FAO/WHO Expert Meetings on Microbiological Risk Assessment) work project in 2000 [2]. The JEMRA was aimed at establishing and optimizing the utility of MRA as a tool to provide actions and decisions for improving food safety with the goal of both developing and developed countries equally using MRA.

In 1997, the European Union Scientific Cooperation group (SCOOP, initiated by France) carried out a microbiological risk assessment of food-borne pathogenic bacteria and toxins. According to a study by Klapwijk in 2000 [10] over the time period 1994–1999, 36.3% of 66 publications came from the US, about half of the publications were reviews, and only seven of the complete microbiological risk assessments were aimed at specific pathogenic bacteria–food combinations:

Notermans *et al.*, Risk of *Bacillus cereus* in pasteurised milk [11]
Brown *et al.*, Risk of *Salmonella* in chicken products [12]
Cassin *et al.*, Risk of *Escherichia coli* O157: H7 in ground beef (beef paste) [13]
FSIS (Food Safety Inspection Service), Risk of *Salmonella* Enteritidis in shell eggs and egg products [14]
FDA, Data survey of *Listeria monocytogenes* risk [15]
Soker *et al.*, Risk of rotavirus in drinking water [16]
Teunis and Havelaar, Risk of *Cryptosporidium* in drinking water [17].

At present, international QMRA studies have mostly covered the whole food chain from the farm to the table. Examples are a risk assessment of *Salmonella* contamination in chicken and eggs in 2002 [8] and a risk assessment of *Vibrio parahaemolyticus* in ready-to-eat raw oysters in 2011 [18]. Studies have also focused on key stages of production processes that cause contamination expansion, such as Smid and coworkers' risk assessment of *Salmonella* contamination in pork slaughtering and processing stages. The objective of the assessment is to find or to evaluate the effect of interventional measures for potentially reducing health risk. By comparison, Chinese QMRA studies mostly involve stages from retail to table and their objective of assessment is to evaluate the size of the health risk. Some examples are Yan Chen and coworkers' study [19], and the CFSA's QMRA study on *Salmonella* contamination in retail raw chicken [20].

Internationally, data sources of QMRA are widespread and include predictive microbiological models or tools, scientific literature, experiment and survey results, and expert heuristics and comprehensive data [21]. With specific food products, the challenge of a storage experiment is used to verify model-infered results and thereby obtain specific data on this food product. In addition, enterprises or industry associations also need to provide market sales data. However, the current key data from Chinese QMRA research have come from results of surveillance or special surveys of food product contamination in the market. The production and processing behavior data and their collection routes are lacking. Surveys with expert heuristics have not been fully carried out, while predictive microbiology models and tools still remain at a scientific research stage, still a bit distant from practical application.

18.1.2.2 China

Comparatively, Chinese food microbiological risk assessment, especially QMRA research, started relatively late. According to a study by Qingli Dong and coworkers [22], literature retrieval has found that the earliest Chinese QMRA study was an assessment on *Vibrio parahaemolyticus* in ready-to-eat raw oysters carried out by Yan Chen and Xiumei Liu in 2006 [23]. The China National Center for Food Safety Risk Assessment (CFSA) launched its first national food microbiological risk assessment study on preliminary quantitative risk assessment of *Salmonella* contamination in raw chicken meat at the retail level and its implications for public health risk in China [20]. This project was part of an assessment report in 2014 which has passed review by the China National Food Safety Risk Assessment Expert Committee. The assessment report is currently being released.

In recent years, food microbiological risk assessment has rapidly developed in China and has received more attention. Since 2011, the CFSA has launched five QMRA studies over four years: *Campylobacter* in raw chicken, *Listeria monocytogenes* in ready-to-eat food, *Vibrio parahaemolyticus* in major ready-to-eat raw shellfish, *Enterobacter sakazakii* and *Bacillus cereus* in infant and young child formula food. Meanwhile, Qingli Dong conducted a search, using “micro*risk*assess” as keywords, in China’s CNKI Database and collected a total of 3700 articles from 2000–2013. Of those, 121 involved Chinese QMRA research. However, in-depth analysis found that only 20 of the studies really involved QMRA computational analysis in relation to health, while others mostly used qualitative or semi-quantitative methods [22].

18.1.3 Applications of Food Microbiological Risk Assessment Results

The application of food microbiological risk assessment is mainly embodied by two aspects: (a) developing a quality control system and (b) setting a food safety objective.

18.1.3.1 Developing a Quality Control System

HACCP (Hazard Analysis and Critical Control Points) is a food safety defense system. It is necessary to fully tap into the potential of HACCP in controlling food-borne diseases and ensuring food safety by further improving its concepts and application. In developing countries, combining food microbiological risk assessment with HACCP has provided realistic results in effectively preventing and controlling the multiplication and spread of pathogenic bacteria during food processing, thereby reducing the hazard of pathogenic bacteria and the occurrence of food safety accidents. The current requirements of Chinese food processing safety controls must be strengthened and the scope of food microbiological risk assessment results must be expanded. Combining food microbiological risk assessment with hazard analysis is a major trend that can develop and implement HACCP. In the near future, the establishment of a modular risk assessment model aimed at quantifying exposure levels of harmful substances in food can provide a more accurate and faster way to conduct food safety control and hazard prevention.

18.1.3.2 Setting a Food Safety Objective

In 2002, the International Commission on Microbiological Specifications for Foods (ICMSF) introduced a new food safety management concept called an FSO (food safety objective) and further explained it based on microbiological risk assessment. Results of quantitative microbiological risk assessment help establish an FSO and can provide some reference for the development of pathogenic bacteria limit standards in food. An FSO refers to the activity of taking certain measures to prevent and eliminate a food safety hazard or to reduce it to an acceptable level. If a food is primarily contaminated by microorganisms and potentially faces secondary contamination and other problems, the FSO is to take certain interventional measures to ensure that, when consumers eat the food, the number of microorganisms is reduced to less than a limit standard. With the help of food microbiological risk assessment process parameters, such as growth rate in a microorganism growth prediction model, food contamination levels at certain points during the circulation process can be calculated. Therefore, food microbiological risk assessment can expand the FSO concept based on a change of parameters. Also, by using a dose-response curve, the disease burden can be obtained when a specific hazard is combined with food and consumers eat the food. Accordingly, an acceptable risk level for the public can be defined as an appropriate level of protection (ALOP). An ALOP refers to the degree of public health protection achieved through a food safety system. The food safety objective on a national level has a certain distance from actual food safety management. The FSO concept proposed by the ICMSF can bridge the gap between ALOP and actual operation to help solve this problem.

In China, food microbiological risk assessment can be applied in the following aspects:

1) Providing scientific evidence for the development or revision of food safety standards;
2) Determining key fields and key species for supervision and management;
3) Finding new factors that may jeopardize food safety;
4) Determining whether certain a factor constitutes a potential food safety hazard; and
5) Other situations in which risk managers should consider the need for risk assessment.

In addition, food microbiological risk assessment can be used to manage the risk of food-borne pathogenic bacteria or viruses based on population health, to deal with food trade disputes, to deal with food safety events and to provide technical support for risk communication, etc.

18.2 Basic Procedures for Food Microbiological Risk Assessment

Microbiological risk assessment includes a four-part framework: (a) hazard identification, (b) hazard characterization, (c) exposure assessment and (d) risk characterization. The FAO and WHO have developed a document intending to provide operable guidelines. The guidelines are neither mandatory stipulations nor necessarily predefined mandatory opinions. In certain respects, it is an advocated method on the basis of expert consensus, providing a modern scientific guiding principle for risk assessment.

In Microbial Risk Assessment Guideline: Pathogenic Microorganisms with Focus on Food and Water, [1] the United States Department of Agriculture Food Safety and Inspection Service (USDA/FSIS) divided methods of food microbiological risk assessment into seven types: (i) screening assessment, (ii) risk rating, (iii) production process analysis, (iv) risk–risk analysis, (v) regional risk assessment, (vi) microbiological risk assessment in sustainability assessment and (vii) vulnerability assessment. The first three are frequently used in food microbiological risk assessment.

On the basis of the "Food Safety Law" [23] (2009 edition), its implementing regulations [24] and "Food Safety Risk Assessment Regulations" (Trial) [25], and by reference to the relevant documents from the CAC and the WHO/FAO about microbiological assessment, the Secretariat of the China National Food Safety Risk Assessment Expert Committee developed the "Food Microbiological Risk Assessment Guideline" (Draft) [26], which stipulates basic food microbiological risk assessment procedures.

18.2.1 Determining a Risk Assessment Project

Before carrying out a food microbiological risk assessment, it is necessary to comprehensively consider the assessment objective, the available information and data, the time for the assessment to be completed and resources (human, financial and other resources) needed to invest in it. Based on the concept of avoiding a complex way, it is necessary to determine a food to be assessed, a microorganism, food–microorganism combination, and an assessment method to be adopted.

18.2.2 Setting up an Assessment Project Group

Institutes and units carrying out food microbiological risk assessment should set up project groups for specific assessments. The professional background of a project group's members should cover microbiology, medicine, agriculture, food and epidemiology, as well as statistics, mathematics and other relevant fields. An expert group is mainly responsible for assessing a scheme, proposing a work suggestion, making important decisions, discussing an assessment report draft and carrying out other work. A working group is mainly responsible for drafting an assessment scheme, collecting the needed data for assessment, carrying out risk assessment, drafting an assessment report and soliciting comments.

18.2.3 Determining Assessment Key Factors

Under normal circumstances, risk managers and risk assessors should determine and analyze key factors of microbiological risk assessment at the initial stage of assessment and decide whether to carry out the risk assessment study. Factors that should be considered include the following:

1) Characteristics and importance of the concerned microbiological hazard;
2) Scope of the impact of this microbiological hazard (contamination rate, contamination density, etc.) and severity of health damage (such as impact on public health, etc.);
3) Status of the concerned population;
4) Other factors related to the hazard of a specific microorganism (such as food processing course, cooking processing, cross-contamination, etc.); and
5) Availability of assessment resources (such as time, funds, personnel, etc.).

18.2.4 Developing an Assessment Implementation Scheme

An assessment implementation scheme is an strategy aimed to carry out food microbiological risk assessment and apply decision-making requirements. In an assessment implementation scheme, the following items are listed:

1) A method that should be used;
2) How a risk assessor integrates data and information from different sources in the risk assessment;
3) How to determine an end point of assessment (such as onset, death, etc.); and
4) Uncertainty in assessment.

An assessment implementation scheme should contain written stipulations about the formed consensus at the assessment stage and about how to carry out risk assessment so as to ensure transparency of the process. With the implementation of risk assessment, the scheme needs to be revised accordingly in order to make a risk management decision. An implementation scheme should also include detailed information on personnel, the expected progress and the required resources.

18.2.5 Collecting Data [27]

In principle, data collection for a food microbiological risk assessment is basically the same as that for a food chemical risk assessment. However, the microbial contamination level in food should be expressed as a colony forming unit number in a unit weight (or volume) of food, that is cfu/g (ml), or as a maximum probable number (MPN). In order to avoid the mixed use of cfu/g (ml) and MPN in the same assessment report, consistency in result expression should be clearly stipulated before data collection. A microbiological risk assessment should give detailed information about a sample, including:

1) Product name (common name or scientific name);
2) Source (country, region, product category, retail, etc.);
3) Sampling method, collection season;
4) Size of each food sample; and
5) Population of sample size.

In addition, it also should describe the genus, species, subspecies and strain that a pathogenic bacterium belongs to, as well as the test method, method variability, method sensitivity and, specifically, the measurement unit of the test result.

Data for a food microbiological risk assessment may come from relevant assessment reports that have been published by international authoritative institutes, the released official information and relevant government reports and national disease surveillance data, as well as animals, food, environment and other surveillance data, peer-reviewed scientific literature, chapters and sections of authoritative books and enterprise-related data, as well as unpublished scientific research data. When information or data is lacking, alternative data or expert opinions and other methods can be used to complement missing data or information.

18.2.6 Hazard Identification and Hazard Characterization

18.2.6.1 Hazard Identification

Hazard identification is the process of qualitatively describing the relationship between a microorganism and its effects. It primarily determines the presence of a microorganism that may cause adverse impact on health in a target food. The vast majority of hazard identification can be determined from known and relevant data, but it needs to include basic information on microbiological hazard (basic characteristics, source, appropriate growth condition, environmental factors affecting their growth and reproduction, etc.), health damage (descriptions of adverse effects on health, determination of the involved susceptible individuals and population, the characteristics and incidence, prevalence, etc. of the disease caused), transmission method (descriptions of the method of microbial transmission and host-infected route) and epidemiological data.

18.2.6.2 Hazard Characterization

Hazard characterization is a process of qualitatively and quantitatively describing severity, duration, influence factors and the dose-response relationship of the adverse health effect caused by a microorganism in ingested food. Hazard characterization needs to describe microbial factors affecting onset risk, such as infectivity, invasiveness and pathogenicity of a microorganism to a host. Also, risk factors must include pathogenesis, transmission characteristics, severity of the caused adverse health effect, possibility of genetic variation, reproducibility in a host body, duration in a host, resistant ability under different control measures, and handling conditions. Further characterization requires food factors and host factors (susceptible individuals/populations, and characteristics influencing population susceptibility such as gender, age, immune status, previous history of infection, nutritional status, host clearance mechanism against microbiological hazard, genetic factors, behavioral characteristics, etc.).

The dose-response relationship is an important part of hazard characterization and can quantitatively describe the relationship between the ingested microbial dose and the adverse host health effect. Building a dose-response relationship model should be based mainly on population studies (epidemiological survey data of a disease outbreak event, annual disease surveillance and onset number statistic data, biomarker studies, population intervention studies, etc.), animal test studies, *in vitro* test studies, expert review, and so on.

18.2.7 Exposure Assessment

Exposure assessment is divided into qualitative assessment and quantitative assessment. Qualitative exposure assessment refers to using a descriptive statement to describe exposure level on the basis of existing data and of information obtained through expert review, while taking uncertainty into account. Quantitative assessment refers to providing a numerical description of exposure and having numerical descriptions for the possibilities of different microbial exposure doses and for the confidence level of exposure estimation. Quantitative exposure assessment is usually divided into point assessment and probabilistic assessment.

Factors to consider while carrying out exposure assessment should include frequency and concentration of microbial contamination in food and the consumption of the food in different populations. Contamination sources and environmental factors should also be considered. With microbial contamination status, the following factors need to be considered:

1) A microbiological test method's sensitivity, specificity, detection limit, sampling method and sample volume;
2) Reasons why microbial contamination in food migh be affected (such as raw material contamination status, food regional difference and seasonality issue, sanitation equipment and process control level);
3) Any one preparation step of food processing method (packaging, marketing, storage, cooking, preservation and others); and
4) Potential dynamic change.

An exposure assessment needs to consider target food consumption frequency and the consumption amount of the whole or specific population during a certain period.

It also needs to understand the population's consumption habits and dietary patterns. Representative dietary consumption survey studies should be included and food yield statistical data can be used to roughly estimate the consumption amount of certain foods. Consumption frequency can be expressed as a proportion of the population who consume the target food during the specific period or the frequency that a certain individual consumes the target food during a specific period. Sales volume, market share and other data can be used to reckon frequency of food consumption too.

18.2.8 Risk Characterization

Risk characterization needs to include: risk estimation result and the assumptions used in extrapolation, confirmation and verification of the assessment result, sensitivity and uncertainty analyses, replies to risk managers' questions, key findings, the main conclusion, the assessment's limitations and any need for further research.

18.2.9 Report Drafting and Review

A risk assessment project group can appoint drafters for various parts of the content and a final author for the entire report. With regard to writing format and content of a risk assessment report, the "Food Safety Risk Assessment Report Writing Guideline" can be referred to [28]. Only after a risk assessment report draft passes review by the China National Food Safety Risk Assessment Expert Committee can it be reported and sent to risk managers. For concrete review procedures and requirements, the "China National Food Safety Risk Assessment Expert Committee Managing Document—Risk Assessment Report Review Procedures" can be referred to [29].

18.2.10 Recording

The assessment process needs to be objectively recorded so as to ensure the transparency of the assessment process and the repeatability of the assessment result.

18.3 Achievements and Shortcomings of Food Quantitative Microbiological Risk Assessment

18.3.1 Achievements of Food Microbiological Risk Assessment

18.3.1.1 Completion of a Number of Food–Microorganism Combination Quantitative Risk Assessments

Since 2009, when the first China National Food Safety Risk Assessment Expert Committee was set up, the committee has completed preliminary quantitative risk assessments of retail raw chicken–*Salmonella* [20], retail raw chicken–*Campylobacter* and ready-to-eat food–*Listeria monocytogenes* combinations, amongst others.

At present, the committee is carrying out risk assessments of the entire processes for major ready-to-eat raw shellfish–*Vibrio parahaemolyticus*, major ready-to-eat raw shellfish–norovirus combinations, infant and young child formula milk powder–*Bacillus cereus*, and infant and young child formula powder–*Cronobacter* genus *Enterobacter sakazakii* combination exposures, amongst others.

This work has played a necessary role in developing or revising food-borne pathogenic bacteria food safety standards, food safety supervision and management, determination of food safety factors, risk communication and other aspects.

18.3.1.2 Construction of a Basic Paradigm of Food Quantitative Microbiological Risk Assessment

Through quantitative risk assessment practice of many food–microorganism combinations, quantitative risk assessment procedures, methods applicable to a Chinese model, and methods and skills for effective risk communication have been established.

18.3.1.3 Exercising a Professional Team for Food Microbiological Risk Assessment

Through the practice of food microbiological risk assessment, a professional team comprising multidisciplinary experts and a work network for food microbiological risk assessment have been formed in China. As a result, the overall capability for food quantitative microbiological risk assessment has been significantly improved. Meanwhile, dominant institutions and teams that participate in food quantitative microbiological risk assessment in China have initially appeared, and the construction of relevant disciplines and key laboratories has also rapidly developed. This has provided preliminary and promising talent for further development.

18.3.1.4 Opening up a Research Field of Food Quantitative Microbiological Risk Assessment

In recent years, research work on food quantitative microbiological risk assessment has rapidly developed [22]. Papers published in native and international academic journals have involved *Salmonella* in eggs [30–32], retail raw chicken [33, 34], *Staphylococcus aureus* in pork and raw milk [35, 36], *Listeria monocytogenes* in bulk cooked meat products and salads [37–39], *Vibrio parahaemolyticus* in short necked clams, *Meretrix meretrix*, and raw salmon, raw oysters and *Portunus trituperculatus* [40–45], *Vibrio vulnificus* in shrimps [22], *Aeromonas* in chilled fresh pork [46], *Pseudomonas* in disinfected milk [22, 47], *Bacillus cereus* in cooked rice and in milk [48, 49], *Campylobacter* in poultry meat [34, 50] and other QMRA studies [51, 52], as well as QMRA studies on mycotoxins and so on [53, 54]. Meanwhile, food quantitative microbiological epidemiological studies, predictive microbiological studies and QMRA technique studies have also been included.

From the viewpoint of published microbiological risk assessment literature, there are considerable differences in depth and structure, and not all literature has complied with the structure and definition of risk assessment in the Codex Alimentarius. Overall, current domestic QMRA research has gradually become popular and development effectiveness has appeared. We firmly believe that with the promulgation and implementation of the "Food Safety Law of the People's Republic of China" (2015 Revision) [55], QMRA will play a greater role and will continue to develop.

18.3.1.5 Carrying Out Effective International Cooperation and Exchange

Around food microbiological risk assessment, there has been effective exchange and cooperation with international organizations and relevant countries' institutions. This includes holding bilateral or multilateral seminars, carrying out joint research, jointly training talent, and performing technical training activities, and so on.

18.3.2 Shortcomings of Food Microbiological Risk Assessment

Although food microbiological risk assessment work has made significant progress, it is not without difficulty, as many aspects still need more effort:

1) Quantitative risk assessment covering the whole food chain for any food–pathogen combination has not been carried out yet, but this kind of assessment has higher value, broader usage and greater guiding significance.
2) Food-borne virus/parasite quantitative risk assessments in food have not been carried out or just have begun. Quantitative risk assessments of important pathogenic bacteria in different food combinations need to be expanded.
3) China is a vast territory and has various regions with big differences. Therefore, carrying out food microbiological risk assessments of regional or local specialty foods and the cooking process behaviors for special foods should be encouraged.
4) The capability for food microbiological risk assessment needs to be strengthened in areas including team scale expansion, professional level elevation, regional or local assessment institute construction, quantitative surveillance system establishment, etc.
5) Food microbiological risk assessment–related discipline construction and talent training should receive more attention and emphasis. Scientific research investment of food quantitative microbiological risk assessment studies, as well as its relevant fields needs to be increased.
6) International cooperation and exchange need to be further strengthened.

18.3.3 Main Problems of Food Microbiological Risk Assessment

Food microbiological risk assessment frameworks are similar, but subtle differences may have a relatively large impact on the results of assessments. The construction of a reasonable and effective risk assessment system needs to start with the effectiveness of a plan, the selection of assessment scope, the pertinence of a problem, the selection of a model and other aspects. Currently, major problems of food microbiological risk assessment include five aspects:

18.3.3.1 The Problem of Making a Clear Assessment Plan and Scope

The objective of food microbiological risk assessment should be made clear and serve the risk managers. USDA-FSIS-EPA (EPA refers to the Environmental Protection Agency in the United States) guidelines have pointed out that making a clear assessment plan is a process of determining the food microbiological risk assessment scope and objective, the problems faced and the methods used, and laying a solid foundation for providing effective risk characterization at a late stage and for judging whether the risk assessment is successful. The guideline also has provided the following different reference factors for determining an assessment project: characteristics and importance of risk; level of risk (such as presence, epidemic, concentrated risk) and severity (such as impact on public health); urgency of the situation; population applicability; other factors related to specific hazards (such as the food processing course, cooking, cross-contamination, etc.); availability of resources (such as time, funds, personnel, etc.). When launching a risk assessment project, the above factors should be comprehensively considered by being combined with the actual situation.

18.3.3.2 The Problem of Hazard Identification

Hazard identification is the first step in a microbiological risk assessment. This preparatory work has become the second technical problem faced by risk managers and risk assessors of food microbiological risk. Hazard identification is usually regarded as a formative stage of a food microbiological risk assessment. Assessment objects, exposure routes, adverse effects, epidemiology and other relevant knowledge are all identified and confirmed at this stage, thus forming the basic framework of assessment. The development of genomics can better explain how a change in environmental conditions in a food chain affects a microorganism and their mutual relationship, which can better serve a food microbiological risk assessment. Reasonable and effective hazard identification can help experts determine whether risk assessment work urgently needs to be carried out.

18.3.3.3 The Problem of Cost-Effectiveness

Carrying out a cost-effectiveness analysis based on the objective of reducing hazards to public health from food-borne pathogenic bacteria is another technical problem. Taking the European Food Safety Authority as an example, Regulation (EC) No 2160/2003 requires that every member country should set an objective for reducing the hazards of zoonotic pathogenic bacteria to the population at different links in the food chain and also requires that the Panel on Biological Hazards of the European Union should carry out a cost-effectiveness analysis within a food microbiological risk assessment. Food microbiological risk assessment studies in the European Union and the US have shown that cost-effectiveness analyses led by risk managers have been successfully used in food microbiological risk assessment studies several times.

18.3.3.4 The Problem of Selecting a Qualitative or a Quantitative Method

According to the output form of the result, a risk assessment can be divided into two major categories: qualitative assessment and quantitative assessment. Before carrying out risk assessment, the appropriate method should be selected according to the principle of avoiding complexity and based on data availability, assessment objective, and depth and breadth when combining risk assessment with risk management or decisions. In addition, obtaining enough valid information and data is the basic premise for improving the accuracy of a risk assessment result. After selecting a quantitative risk assessment, the introduction of both a microbial growth prediction model at the exposure assessment stage, and the introduction of a dose-response model at the hazard characterization stage should be done very carefully because, if the right model is not introduced, the risk assessment may be inaccurate or even give the opposite result.

Also, if it is difficult to judge which method of food microbiological risk assessment should be selected, a qualitative risk assessment of the pathogenic bacterium can be implemented first. If the result of the qualitative analysis shows that the bacterium is a relatively large hazard to the population, qualitative assessment may prove to be relatively simple and feasible. In some cases, quantitative risk assessment is not necessarily better than qualitative risk assessment. Therefore, based on the actual situation, a simple form of assessment should be selected as far as possible under the premise of ensuring accuracy of the assessment result. In summary, regardless of the use of assessment methods, the process should strictly comply with assessment steps. When qualitative risk assessment does not meet risk management requirements, collecting enough information and data should be considered for implementation of a quantitative risk assessment of the pathogenic bacterium.

18.3.3.5 The Problem of Risk Modeling Research

A microbial prediction model and a dose-response model are usually applied at the microbiological hazard characterization stage to assess the impact of a specific hazard on a specific population. The development of computer technology and predictive microbiology, amongst other things, has promoted rapid development of risk modeling and has made a microbiological predictive model and a dose model two important components of food microbiological risk assessment, especially with quantitative assessment. A microbiological predictive model is used to describe the impact of environmental factors on a microbial number at different links in a food chain, such as processing, marketing, transportation, consumption and other processes. It becomes an essential component of exposure assessment and databases and powerful software can greatly facilitate construction of such models.

A dose-response model is an important model for food microbiological risk assessment at hazard characterization stage and is used to describe the relationship between hazard exposure at individual or population levels and adverse health status (such as infection, disease and death). For example, a β-Poisson model and an exponential model are two models that are most frequently used in international food microbiological risk assessment. In 2011, the European Food Safety Authority used them to research interventional measures for reduction of *Campylobacter* hazards. The two models are based on the same assumption that a single kind of microorganism causes the same or similar hazard to the body, but both the exponential model and the β-Poisson model use a model parameter to represent uncertainty of interaction between bacteria and host. When applying the above dose-response model, caution should be taken because it is not applicable to all pathogenic bacteria that produce toxins and cause disease.

Recruiting human volunteers to carry out a human trial is a relatively accurate method to establish a dose-response model. Existing studies have been carried out on human volunteers with pasteurized milk exposed to different doses of *Bacillus cereus*. However, due to legal restrictions, scientific ethics and complex application procedures in the practice process, studies using human trials to build an accurate dose-response model still face great difficulties. Unusually low exposure levels of pathogenic bacteria also increase the difficulty of building a dose-response model. Carrying out comprehensive and integral quantitative risk assessment for pathogenic bacteria remains a difficult achievement in many cases. Meanwhile, it is imperative that a dose-response model applicable to a country's own conditions is established as soon as possible.

18.4 Future Outlook for Food Microbiological Risk Assessment

Risk assessment is a core component of risk analysis and its importance is self-evident. While it is also a relatively new branch of a risk analysis system, from either the policy perspective or at a technical level, it still needs further improvement. In addition, the work is a heavy task and has a long way to go. Developing countries need to strengthen microbiological risk assessment so as to narrow the gap with developed countries [22].

Food microbiological risk assessment has become an important scientific tool to cope with current food safety issues. When launching a food microbiological risk assessment project, legal and technical factors should be fully considered and an appropriate assessment method should be rationally selected. Strengthening interactive communication between risk management and risk assessment, further improving risk surveillance, improving the establishment of microbial limits and strengthening international cooperation can effectively promote implementation and enforcement of the "Food Safety Law of the People's Republic of China" (2015 Revision) which was promulgated in 2015 [55]. It can have great significance for implementing food risk prevention and control measures, and achieving food safety objectives and further protecting public health.

18.4.1 Strengthening the Interaction between Risk Assessment and Risk Management

The launch of a risk assessment generally comes from a task entrusted by risk managers and from self-determined assessment objectives according to the current food safety situation. The aforementioned technical factors, public food safety requirements and so on are all factors that should be considered when commencing a food microbiological risk assessment study, but are not decisive factors. Before formally launching a risk assessment project, risk managers and relevant experts need to analyze the food safety issues to be assessed and determine the necessity of risk assessment. They need to determine hazard factors and the foods involved, consumer exposure routes and their possible risk, consumer awareness of the risk and the existing international risk control measures, among other issues. Therefore, strengthening interaction and communication between risk assessment and risk management is quite necessary.

Taking the China National Center for Food Safety Risk Assessment as an example, in early 2013, based on domestic retrieved data, quantitative risk assessments of *Vibrio parahaemolyticus* in raw fresh shellfish and *Listeria monocytogenes* in ready-to-eat food were launched. These two resolutions formed in early 2012 and were aimed at verifying whether risk assessments could be effectively implemented according to internationally accepted guidelines, while providing theoretical references for food safety regulators. In the future, the importance of exchange and cooperation between risk assessors and risk managers will be more prominent. The work to improving food microbiological risk assessment guiding principles applicable to Chinese conditions urgently needs to be carried out.

18.4.2 Improving Risk Surveillance

Lack of risk surveillance data is one of the core problems restricting implementation of a risk assessment study. Food microbiological risk assessment should determine the exposure of populations and high-risk populations, then predict and analyze microbial growth, survival and cross-contamination, and so on under food processing, storage, transportation and other conditions as far as possible. To do so, the assessment should select a pathogenic bacterium–food combination, investigate and research the food consumption amount, consumption frequency, prevalence data and other information. Then, it should estimate the pathogenic bacteria contamination level in the food and the population exposure level before quantitatively assessing adverse health effects, and so on. In recent years, data collection has made progress through the joint efforts of various departments, but more representative data that can reflect the uncertainty of microbial contamination need to be obtained.

As in many countries, the China National Center for Food Safety Risk Assessment and other relevant scientific research academies and institutions have also established a national laboratorial surveillance network for bacterial infectious disease molecular typing and genomics. This network will provide key support technology for the development direction of Chinese laboratory pathogenic bacteria surveillance in the future. This risk surveillance should gradually develop so as to cover the whole industry chain. In order to achieve this objective, large multidepartment collaboration and large-scale data integration, mining, and applications are needed to greatly improve the ability and speed of monitoring and handling infectious disease epidemic situations and public health emergencies, thereby providing references for food microbiological risk assessment.

18.4.3 Improving Legal Limits

The FSO/ALOP, which is the basis of food microbiological risk assessment, is an important reference for the establishment of relevant microbiological standards. Taking risk assessment of *Listeria monocytogenes* in ready-to-eat food as an example, the legal limit of *Listeria monocytogenes* in ready-to-eat food had been developed by a using secondary sampling method recommended by ICMSF as early as in 1986. At present, China and other foreign countries have completed several quantitative assessments, and the results can be directly converted to an FSO, with the conclusion usually being that the number of *Listeria monocytogenes* in ready-to-eat food should be less than 100 CFU/g. However, the development of an FSO still faces some difficulty as not all pathogenic bacteria have been set legal limits. Converting an FSO to a legal microbial limit should be carefully done and legal limts for pathogenic bacteria according to national food safety standards should be developed very cautiously too.

After China promulgated its “Food Safety Law” in 2009, the National Health and Family Planning Commission of the People’s Republic of China published a draft of microbial limit standards in food in December 2010, then formally implemented it in 2014. The standard covered 17 large categories of common foods in the Chinese import and export trade and stipulated limit level values according to different sampling methods for several types of quite harmful food-borne pathogenic bacteria, such as *Salmonella*, *Listeria monocytogenes*, *Staphylococcus aureus*, *Shigella*, and so on. In addition to the standard, China has another guiding standard in the Guideline for the Application of Food Microbiological Risk Assessment in Food Safety Risk Management (GB/Z 23785-2009). This technical guiding document provides the general framework for food safety risk management, as well as a guiding method for the application of food microbiological risk assessment in food safety risk management. How to scientifically and effectively develop a microbial limit standard based on risk according to food microbiological risk assessment is still a focus of future effort.

18.4.4 Strengthening International Cooperation

Strengthening risk communication and international cooperation worldwide is also one of the important tasks of risk managers. Based on risk, various countries should scientifically and systemically establish safety control measures from farm to table. China is one of the largest producers and consumers of agricultural products in the world, so risk assessment will become a core component of its food safety management. China should achieve cooperation with international or regional organizations or other countries in the food safety risk assessment operation mechanism. Scientifically, it should use theoretical risk assessment tools and mathematical modeling, while strengthening comprehensive coordination and further improving the food safety regulatory system.

References

1 US Department of Agriculture (USDA)/Food Safety and Inspection Service (FSIS) (2012) Microbial Risk Assessment Guideline: Pathogenic Microorganisms with Focus on Food and Water. USDA/FSIS/2012-001.

2 World Health Organization, Food and Agriculture Organization of the United Nations, (WHO/FAO) 2003: Guidelines on Hazard Characterization for Pathogens in Food and Water. http://apps.who.int/iris/bitstream/10665/42693/1/9241562374.pdf (accessed Novemver 2016).

3 Codex Alimentarius Commission (CAC) (1999) Principles and Guidelines for the Conduct of Microbiological Risk Assessment, CAC/GL-30(1999). http://down.40777.cn/stardard/10/CAC-GL-30%20PRINCIPLES%20AND%20GUIDELINES%20FOR%20THE%20CONDUCT%20OF%20MICROBIOLOGICAL%20RISK%20ASSESSMENT.pdf (accessed November 2016).

4 US Department of Agriculture's Food Safety and Inspection Service (1998) *Salmonella* Enteritidis Risk Assessment, Shell Eggs and Egg Products. Washington, DC.

5 US Food and Drug Administration (2000) Draft Risk Assessment on the Human Health Impact of Fluoroquinolone Resistant *Campylobacter* Associated with the Consumption of Chicken. (Revised January 5, 2001.)

6 US Food and Drug Administration, and Food Safety and Inspection Service (2001) Draft Assessment of the Relative Risk to Public Health from Foodborne *Listeria monocytogenes* Among Selected Categories of Ready-to-Eat Foods. www.foodsafety.gov (accessed November 2016).

7 US Food and Drug Administration (2001) Draft Risk Assessment on the Public Health Impact of *Vibrio parahaemolyticus* in Raw Molluscan Shellfish. www.foodsafety.gov (accessed November 2016).

8 World Health Organization and Food and Agriculture Organization of the United Nations (2002) Risk Assessments of *Salmonella* in Eggs and Broiler Chickens. *Microbiological Risk Assessment Series* 2.

9 World Health Organization (2016) Microbiological Risk Assessment Series http://www.who.int/foodsafety/publications/risk-assessment-series/en/ (accessed November 2016).

10 Klapwijk PM, Jouve JL, Stringer MF. (2000) Microbiological risk assessment in Europe: the next decade. *Int J Food Microbiol*, 58:223–230.

11 Notermans S, Dufrenne J, Teunis P, *et al.* (1997) A risk assessment study of *Bacillus cereus* present in pasteurised milk. *Food Microbiol*, 14:143–151.

12 Brown MH, Davies KW, Billoon CMP, *et al.* (1998) Quantitative microbiological risk assessment: principles applied to determining the comparative risk of salmonellosis from chicken products. *J Food Protect*, 61:1446–1453.

13 Cassin MH, Lammerding AM, Todd ECD, *et al.* (1998) Quantitative risk assessment for *Escherichia coli* O157: H7 in ground beef hamburgers. *Int J Food Microbiol*, 41:21–44.

14 FSIS (Food Safety Inspection Service) (1998) *Salmonella* Enteritidis Risk Assessment. Shell Eggs and Egg Products. http://www.fsis.usda.gov/OPHS/risk/pdfrisk1.pdf (accessed November 2016).

15 FDA (1999) Structure and initial data survey for the risk assessment of the public health impact of foodborne *Listeria monocytogenes*. Preliminary information is at http://vm.cfsan.fda.gov/~dms/listrisk.html (accessed November 2016).

16 Soker JA, Eisenberg JN, Olivier AW. (1999) Case Study: Human Infection Through Drinking Water Exposure to Human Infectious Rotavirus. ILSI Research Foundation. Risk Science Institute, Washington.

17 Teunis PFM, Havelaar AH. (1999) *Cryptosporidium* in drinking water: Evaluation of the ILSI/RSI quantitative risk assessment framework. Report 284-530-006, National Institute of Public Health and the Environment, Bilthoven, The Netherlands.

18 World Health Organization and Food and Agriculture Organization of the United Nations (2011) Risk Assessment of *Vibrio parahaemolyticus* in Seafood. *Microbiological Risk Assessment Series* 16.

19 Chen Y, Liu XM. (2006) Quantitative risk assessment of *Vibrio parahaemolyticus* in retail raw oysters in Fujian. *Chin J Food Hygiene*, 18:103–108 [in Chinese].

20 China National Committee for Food Safety Risk Assessment (2015) Preliminary Risk Assessment of *Salmonella* Contamination in Chicken Meats at the Retail Level and Its Implications for Public Health Risk in China.

21 International Life Sciences Institute (2012) Tools for Microbiological Risk Assessment. ILSI Europe Report Series.

22 Dong QL, Barker GC, Gorris LG, *et al.* (2015) Status and future of quantitative microbiological risk assessment in China. *Trends Food Sci Technol*, 42(1):70–80.

23 State Council (2009) Food Safety Law of the People's Republic of China. February 28, 2009 [in Chinese].

24 State Council (2009) Implementing Regulations of Food Safety Law of the People's Republic of China. July 20, 2009.

25 Former Food Safety Integrated Coordination and Health Inspection Bureau, Ministry of Health (2010) Food Safety Risk Assessment Regulations (Trial). Weijianfa (Ministry of Health Inspection and Promulgation [2010] No. 8. January 21, 2010.

26 China National Food Safety Risk Assessment Expert Committee. Food Microbiological Risk Assessment Guideline (Draft).

27 China National Food Safety Risk Assessment Expert Committee (2010) Food Safety Risk Assessment Data Needs and Collection Requirements. November 2010.

28 China National Food Safety Risk Assessment Expert Committee (2010) Food Safety Risk Assessment Report Writing Guideline. November 2010.

29 China National Food Safety Risk Assessment Expert Committee (2009) Risk Assessment Work Procedures of China National Food Safety Risk Assessment Expert Committee. December 2009.

30 Zhao ZJ, Liu XM. (2004) The modeling of quantitative risk assessment on *Salmonella* in shell eggs in China Part I: Hazard identification and exposure assessment. *Chin J Food Hygiene*, 16(3):201–206 [in Chinese].

31 Zhao ZJ, Liu XM. (2004) The modeling of quantitative risk assessment on *Salmonella* in shell eggs in China Part II: Description of characteristics of hazard and risk. *Chin J Food Hygiene*, 16(4):295–300 [in Chinese]

32 Mao XD, Hu JF, Liu XM. (2011) Estimation on disease burden of foodborne non-typhoid Salmonellosis in China using literature review method. *Chin J Dis Control Prevent*, 15(7):622–625 [in Chinese].

33 Zhu JH, Wang YR, Song XY, *et al.* (2014) Prevalence and quantification of *Salmonella* contamination in raw chicken carcasses at the retail in China. *Food Control*, 44:198-202.

34 Huang JL, Zong Q, Zhao F, *et al.* (2016) Quantitative surveys of *Salmonella* and *Campylobacter* on retail raw chicken in Yangzhou, China. *Food Control*, 59:68–7.3

35 Luo X, Guo HW, Wang Y, Li J. (2010) Quantitative risk assessment on *Staphylococcus aureus* in pork in Shanghai. *Chin J Food Hygiene*, 22(3):244–249 [in Chinese].

36 Wen J. (2008) Risk assessment of *Staphylococcus aureus* in raw milk. Harbin: Northeast Agricultural University, 2008 [in Chinese].

37 Tian J, Fan YX, Liu XM. (2011) Quantitative risk assessment of *Listeria monocytogenes* in bulk cooked meat products. *Chin J Prevent Med*, 45(6):537–542 [in Chinese].

38 Tian J, Liu XM. (2009) Risk assessment of *Listeria monocytogenes* in foods. *Chin J Food Hygiene*, 21(5):468–472 [in Chinese].

39 Dong QL, Zheng LM, Dang WX, Gu XT. (2012) Semi-quantitative risk assessment of *Listeria monocytogenes* in RTE food. *Sci Technol Food Ind*, 33(11):321–323, 366 [in Chinese].

40 Mao XD, Hu JF, Liu XM. (2013) Study on Chinese incidence of foodborne disease caused by *Vibrio parahaemolyticus* by literature review method. *Chin J Dis Control Prevent*, 17(3):265–267 [in Chinese].

41 Shao YF, Wang W, Zhang RH, *et al.* (2010) Risk assessment of *Vibrio parahaemolyticus* in ready-to-eat raw oysters in Zhejiang. *J Chin Inst Food Sci Technol*, 10(3):193–199 [in Chinese].

42 Ning Q, Li SS, Chen SP. (2010) Risk assessment of *Vibrio parahaemolyticus* in *Meretrix. Mod Food Sci Technol*, 26(11):1259–1263, 1292 [in Chinese].

43 Gao WW, Liu H, Liu C, *et al.* (2010) Contamination of *Vibrio parahaemolyticus* in *Portunus trituperculatus* in Shanghai retail markets and its risk assessment. *Chin J Food Hygiene*, 22(4):371–374 [in Chinese].

44 Shou S, Wu YJ, Ning Q, *et al.* (2012) Quantitative risk assessment of *Vibrio Parahaemolyticus* in short necked clam. *J Beijing Technol Bus Uni (Nat Sci)*, 30(5):38–45 [in Chinese].

45 Liu H, Luo BZ, Qin LX, *et al.* (2012) Quantitative risk assessment study of *Vibrio parahaemolyticus* in ready-to-eat raw salmon slices. *Chin J Food Hygiene*, 24(1):18–22 [in Chinese].

46 Dong QL, Gao C, Zheng LM, Hu MH. (2012) Quantitative exposure assessment of *Aeromonas spp*. in chilled pork. *Food Sci*, 33(15):24–27 [in Chinese].

47 Qiu J, Dong QL, Cheng F. (2012) Establishment of a growth probability model for *Pseudomonas spp*. in chilled pork with modified atmosphere package. *Trans Chin Soc Agri Eng*, 28(13):257–262 [in Chinese].

48 Dong QL. (2013) Exposure assessment for *Bacillus cereus* in Chinese-style cooked rice. *J Food Process Eng*, 36(3):329–336 [in Chinese].

49 Chu XJ, Feng LG, Zhang Y, Xiao X. (2006) Risk assessment of *Bacillus cereus* in pasteurized milk. *Chin Dairy Ind*, 34(6):23–26 [in Chinese].

50 Zhai WH. (2011) Epidemiological and quantitative risk assessment study on *Campylobacter* in poultry meat from farm to table. Masters thesis. Yangzhou University [in Chinese].

51 Mao XD, Hu JF, Liu XM. (2011) Epidemiological burden of bacterial foodborne diseases in China-preliminary study. *Chin J Food Hygiene*, 23(2):132–136 [in Chinese].

52 Pei XY, Guo YC, Ning Li, *et al.* (2015) 2012 Chinese food microbiological risk surveillance overview. *Chin J Publ Health Manag*, 1:25–28 [in Chinese].

53 Zhao XB, Schaffner DW, Yue TL. (2013) Quantification of aflatoxin risk associated with Chinese spices: point and probability risk assessments for aflatoxin B1. *Food Control*, 33(2):366–377.

54 Han Z, Nie DX, Yang XL, *et al.* (2013) Quantitative assessment of risk associated with dietary intake of mycotoxin ochratoxin A on the adult inhabitants in Shanghai city of P.R. China. *Food Control*, 32(2):490–495.

55 State Council (2015) Food Safety Law of the People's Republic of China. April 24, 2015 [in Chinese].

19

Food Safety Risk Communication Practices and Exploration in China

Kai Zhong[1] *and Yue Zheng*[2]

[1] *China National Center for Food Safety Risk Assessment, Beijing, China*
[2] *Commercial Food Sanitation, LLC, USA*

19.1 The Importance of Food Safety Risk Communication

Risk communication is a concept that first appeared in the 1980s and has gradually evolved into an emerging science involving multiple disciplines. Early stage risk communication primarily focused on one-way dissemination of information or propaganda. The main purpose was to inform, educate and persuade. Later on, people gradually realized the shortcomings of one-way communication, and therefore established the "interactive" features of risk communication.

During the 1990s, the World Health Organization (WHO) proposed the concept of a food safety risk analysis framework [1], which was considered to be the scientific method to solve all food safety issues. The framework includes risk assessment, risk management, and risk communication. In 2006, there was a significant change in the structure of food safety risk analysis [2] from the original triple Venn diagram to risk assessment and risk management becoming subsets of risk communication (Figure 18.1). This change indicated the realization by the academic community of the importance of risk communication.

Food Safety Risk Analysis – A Guide for National Food Safety Authorities [3], published by the World Health Organization/United Nations Organization (WHO/FAO), clearly defines risk communication as "the interactive exchange of information and opinions throughout the risk analysis process concerning risk, risk-related factors and risk perceptions, among risk assessors, risk managers, consumers, industry, the academic community and other interested parties, including the explanation of risk assessment findings and the basis of risk management decisions".

The risk analysis framework was officially introduced into China about ten years ago. The risk assessment technical system has gradually improved, and specialized organizations such as the National Food Safety Risk Assessment Committee have been established [4]. Regulations and standards-based government regulatory systems, and HACCP and GMP-based food processor quality management systems have been introduced. However, the development of risk communication has lagged behind and become the weak link in the risk analysis system.

Food Safety in China: Science, Technology, Management and Regulation, First Edition.
Edited by Joseph J. Jen and Junshi Chen.

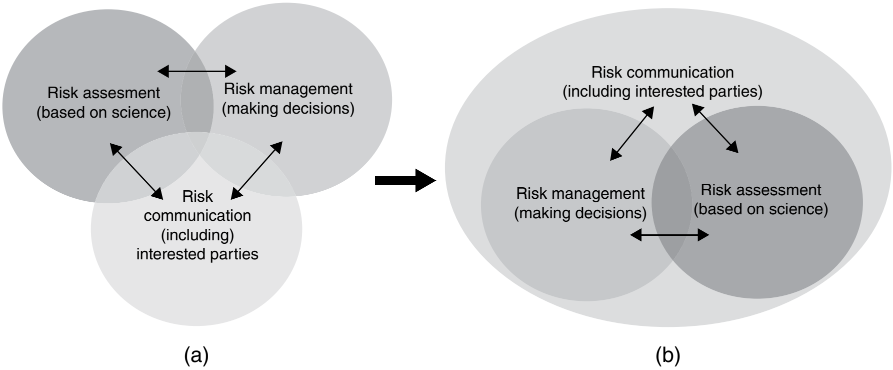


Figure 19.1 The evolution of the risk analysis framework. *Source:* Data adopted from references [1, 2].

Risk communication, as an important component of the risk analysis framework, plays the role of both adhesive and lubricant in the whole process of risk assessment and risk management. Risk communication is a crucial channel for food processors, regulators, consumers, and other interested parties to exchange views, then reach a consensus. It can significantly enhance regulatory efficiency, maintain consumer confidence, and promote industry sustainable development, as well as becoming a necessary requirement for fulfilling the target of participation by all segments of the society.

The primary goal of risk communication is to promote risk information awareness and understanding of various interested parties and leverage their cognitive differences by building a bridge between scientists, managers, media, and the public. Food safety involves a long chain of disciplines from front-end subjects, such as environment and agriculture, to rear-end subjects such as public health and medical care. The goal of risk communication is to avoid over-reaction or other irrational attitudes and behavior generated by misreading and misunderstanding.

Secondly, risk communication promotes effective implementation of risk management measures. For one thing, risk communication between risk assessors and risk managers helps managers properly understand the scientific connotations of risk assessment and therefore make science-based decisions based on scientific facts. On the other hand, risk management measures require a timely, broad, and comprehensive opinion exchange between interested parties, so that all parties can understand the rationale behind the decision-making process and the significance of management practices. It effectively reduces controversy in the implementation of risk management, and improves risk management feasibility, rationality, and effectiveness.

Risk communication also helps to improve public confidence in food safety. The public losing confidence and the lack of trust in food safety systems greatly contribute to the current status of public opinion on food safety. Risk communication is a critical tool to rebuild confidence and reshape an image. Only long-term unremitting responsible action, working in a transparent and open manner with good risk communication tools, can rebuild consumer confidence in media reporting. Undoubtedly, the negative impact has been deeply rooted in the public. It is by no means an easy thing to reverse public perception.

In addition, risk communication is also conducive to promoting the sustainable development of food manufacturing, industry, and trade. The development of the food industry and trade eventually benefits all consumers, but this accomplishment would not be achieved without good public opinion and consumer awareness. The fact that long-term absence of risk communication and lack of consumer confidence have had a negative impact on the food industry in China, which has not yet completely recovered from the melamine incident.

Trust is the foundation of effective risk communication. However, the severe acute respiratory syndrome (SARS) crisis in 2003 tremendously damaged the Chinese Government's credibility. For the food industry, the 2008 melamine incident was the tipping point [5]. The melamine incident was the landmark for food safety. It not only promoted the legislative progress of the Food Safety Law, but also had a profound impact on food safety risk communication.

Following the "Shanghai hepatitis A pandemic," the melamine incident was the largest food safety event in China, resulting in hundreds of thousands of children suffering kidney stones. The deliberate concealment of the truth by the responsible company and local government not only worsened the crisis, but also left consumers with a loss of trust in the entire food regulatory system and food supply system. Since then, media coverage for food safety issues has become intense. "Food safety" has become the topic of most concern to the public during the National People's Congress and the Chinese Political Consultative Conference for many years.

After the melamine incident, continuous media reports completely destroyed consumers' confidence in the domestic dairy industry. Imported milk powder occupied the majority of the Chinese market, and the phenomenon of Chinese consumers buying up milk powder overseas appeared. While the government and industry have used a variety of remedies to try to recover the image of the China dairy industry over the years, these efforts have not been recognized by consumers. Government regulators, industry, and companies have increasingly realized that food safety is not all about risk management. Risk communication is the key to untie the knot of credibility.

19.2 Genetically Modified Organisms (GMOs) and Consciousness of Public Rights

The core issue of GMO risk communication is the public's right to know, from which is derived the right to choose. Both of them are part of the awakening consciousness of civil rights. It is an irresistible trend accompanying economic and social development. However, due to the high level of technology involved, neither the administration nor academia has been aware of the necessity of letting the public know and understand GMOs. Therefore, the country has invested billions of research funding in GMOs, but there has been little or no funds supporting risk communication research and practices.

Because the need for the right to know has not been effectively met, related research and scientists have been repeatedly bombarded by public opinion. The Internet is also filled with rumors and conspiracy theories. Being questioned by the public and the media, the vast majority of GMO researchers and relevant departments cannot always actively respond and communicate, and therefore let the "anti-GMO party" spread rumors by using asymmetric information between domestic and international policies. Some of the "pro-GMO party" educate the public in an unquestionable "scientific chauvinist" manner in order to promote it. This move has undermined the equal atmosphere of communication and conversation with the public, leading to strong emotional opposition. Various factors have intertwined step by step, finally resulting in the notorious GMO situation.

Although basic research into GMOs seems to have not been substantially impacted, due to the lack of public acceptance of GMOs, relevant research results are still in bud in experimental plots and thus cannot be presented and actually generate productivity. Under conditions where the right to know cannot be met, consumer pursuit of the right to choose ends up with a "not- in-my-back-yard" mindset. With the strong voice of public opinion, China has adopted a very stringent GMO labeling policy, which has brought in immeasurable social costs to promote GMOs. Some researchers have not even been able to start their normal research work with this notorious atmosphere. For example, the "golden rice" incident in 2012 occurred only because researchers attempted to avoid the panic of voluntary testers. Researchers intentionally concealed the fact that "golden rice" was a GMO crop, despite it being a serious violation of scientific ethics. The incident also reflects that risk communication regarding GMOs is a long-standing failure.

19.3 The Rise of the New Media Era and Opinion Leaders

The media plays a vital role in food safety risk communication. The communication tool has continuously shifted between traditional media and new media in the past decade; we have witnessed the personal computer terminal gradually being replaced by the mobile phone. Also, there has been a rise and fall of the number of opinion leaders. After 2008, consumers were afraid of their own shadow when talking about food safety. The "Grassroots" featured and represented the voice of the people, new media rapidly magnified the public's "insecurity about food" like pouring oil on a fire.

After 2009, with the explosive growth of micro-blogging, communication patterns experienced a fundamental change. A new communication pattern of "micro-blogging starting hot topics – traditional media following-up–micro-blogging spreading" process was gradually emerging. Whistle-blowing and complaining about food safety often became a hot topic in micro-blogging. In 2011, the Shineway clenbuterol incident, the Taiwan cloudy agent incident, the Shanghai tainted steam bun incident, the waste oil incident, the Ajisen Ramen soup incident, and many other negative events took place. This caused a peak in Internet discussion of food safety. After that, the public gradually became "desensitized" to negative reports on food safety, and the Internet discussion gradually declined.

In 2011, the launch of WeChat (a mobile text and voice messaging communication application) brought new challenges to communication patterns. In 2013, WeChat users expanded to 600 million. Besides micro-blogging, another fermentation tank for food safety opinions appeared. As the nation deepened initiatives to combat Internet rumors and cyber-extortion, a number of food safety rumor-makers were arrested. Food safety public opinion was filtered to a certain degree. However, rumors have not completely disappeared, but the main battlegrounds have shifted from micro-blogs to WeChat. The relatively closed communication path of a WeChat friend circle makes it difficult for the refuting of rumors to reach the target audience, but also makes it more difficult to track the source of rumors.

With the development of self-media and the dispersion of the right to speak, some influential people on the Internet with tremendous numbers of followers began to show their dominating influence on public opinions, even superseding that of traditional media. Because of the silence of food science academia, some so-called "opinion leaders" gradually took over the public discourse, and became the driving force for negative information. They generated panic and blackmailed food companies by exaggerating facts, and disguised replacement of information, resulting in a severe impact on society.

For example, "environmental expert Mr. Dong, Liang Jie" spread the rumor that antibiotics had been detected in tap water and caused public panic, in order to promote the sales of his water purification equipment. The "International Food Packaging Association" (note: actually a private company registered in Hong Kong) General Secretary, Dong Jinshi, frequently appeared in front of the camera for the sake of "cracking down on counterfeit goods." His speeches covered a number of areas concerning food safety, nutrition, and environmental protection, so as to hijack public opinion and blackmail companies negatively affected by news. Until 2013, he claimed that he had been interviewed by the media over 5000 times, and had been hailed as the chief food safety advisor by more than 100 domestic media (note: the above two people have been arrested by the police).

Facing intensifying rumors of food safety concerns, a number of young scholars from food science academia began to fight back, crack down on rumors, and clarify the facts on the Internet through scientific accuracy and plain language. New opinion leaders on food safety gradually stepped onto the stage. For example, Dr. Wuxin Yun from the Scientific Squirrels Association of Science Communicators, and Dr. Kai Zhong from the National Food Safety Risk Assessment Center become active in micro-blog and media columns, writing opinions and comments for hot food safety topics. They played critical roles in responding to a series of food safety incidents such as "slush ice is dirtier than toilet water," "Fonterra outline contamination," and "Shanghai Husi."

19.4 The Proposal of Social Participation and the Concept of Cooperated and Joint Efforts

Food safety is not limited to government regulators and food producers. It should be a "project" with the participation of every citizen. Between 2008 and 2013, China's government has transformed from working internally to "cooperative and joint efforts to maintain food safety," social participation. Cooperation and joint efforts have gradually become the mainstream for food safety administration. In the past few years, risk communication also has started to take shape: relevant research institutes, societies, associations, social institutions, the media, and other parties jointly participate in risk communication, with the government in the lead.

The scientific community is the vanguard of food safety risk communication. For example, the Chinese Institute of Food Science and Technology (CIFST) uses its professional advantage to promote to the public the return to rationality, by organizing renowned experts, scholars, and the media to analyze and review "food safety incidents" in past years. Once a food safety incident occurs, they will actively contact industry experts to explain the situation and clarify the rumors. They also encourage companies and young students in food-related majors to deliver current food safety knowledge by organizing current food safety education contests with text, images, animation, and other forms of expression.

Young scholars studying journalism and communication from Fudan University, Tsinghua University, Peking University, Nanjing University, and other research institutions co-founded the alliance of "Food and Drug Safety Journalism and Communication for Young Scholars" [6]. They target communication strategy study, food safety case study, and other aspects to provide theoretical references for government regulatory authorities, research institutions, and the industry.

Some popular science authors spontaneously founded a scientific squirrel web site called "Guokr". The web site brings together a large number of young scholars from universities and research institutions to promptly track social trending topics by way of "user-generated content". The "Myth Buster" section of Guokr has cracked a lot of rumors in the field of food safety. Information provided on "Myth Buster" is very well received among young people. With the help of CCTV and other traditional media, the starting and spreading of rumors within society have been reduced.

Risk communication values the role of third parties in the science community internationally. For example, the China Food Information Center (CFIC) has now been established after several years of preparation [7]. It presents a voice for China in the International Food Information Center (IFIC). Although the CFIC does not have a long history, expectations are high. Currently, the CFIC is still in the early stages of development and has gradually begun to play a liaison role between regulatory authorities, the scientific community, the media, and industry.

Traditional media plays an important role as a bridge in food safety risk communication. For example, "Southern Weekend" launched the "Health Statement" plan [8], including young scholars and practitioners in food safety, public administration, law, communication, and other areas. The plan of regularly hosting seminars to review food safety hot topics not only spreads the spirit of science, rational thinking, and law philosophy to society, but also acts as a communication bridge between researchers, businesses, and regulators. These measures can positively drive the reform of public opinion on the food and drug regulatory system, food safety information disclosure, and other aspects.

The China Economic Net (CEN) launched "Food Safety Forum30" [9], which covers all segments of professional and food safety experts in the field of media research, which had an active effect on news release, information communication, risk communication, decision-making advice, and media training. The "China Food Safety News" has a dedicated risk communication edition, which not only introduces theoretical knowledge and practical skills, but also encourages food regulators to learn from each other by organizing essay competitions [10].

The media not only has in-depth coverage on high-quality food, excellent brands, excellent businesses, and outstanding individuals, but also focuses on major policies and measures that are issued by the government to strengthen food safety supervision, fight against illegal activities, and other aspects. For example, the "Interpretation of jeopardy food safety criminal cases applicable to a number of issues" and the report on typical cases, strongly deter criminals and encourage the whole society to further improve food safety awareness and enhance the public's confidence in food safety.

19.5 The Germination Stage of Government Agencies Risk Communication System

To promote risk communication, the concept needs to be updated and responsibility needs to be clearly defined. Encouraged by academician Jun Shi Chen, the concept of risk communication has gradually been understood and recognized by food safety professionals. In 2009, the Nutrition and Food Safety Institute of China Disease Prevention and Control Center founded a risk communication office and started developing a risk communication system from ground zero. In October 2011, the National Food Safety Risk Assessment Center was founded. It has established a dedicated risk communication department and allowed China's first independent food safety risk communication team to be born.

Since the establishment of the Risk Communication Department, a positive effort has been made and admirable results achieved on public opinion supervision and response, scientific education, and development of risk communication system construction [11]. The department extensively organizes science educational activities for schools, communities, and the media. An Open Day allowed the public to communicate with scientists face to face. Scientific knowledge was delivered in the form of blogs, micro-blogs, info graphics, and videos, which were very popular with the public. For those typical misunderstandings that exist in public opinion, concerns were responded to with the data, pictures, and the truth.

With the advancement of food regulatory reform, relevant government departments are gradually establishing dedicated news propaganda agencies and risk communication departments. Besides the Information Department, the China Food and Drug Administration also explicitly defines risk communication functions for the Department of Food Safety Supervision.

19.6 The Food Division of the Health and Family Planning Commission has Set Up a Risk Communication Position

Government departments focused on strengthening the release of food safety authority information, putting forward efforts to solve the lack of confidence in food safety caused by asymmetric information. Comparing 2013 with previous years, the amount of released information, media coverage, and publication frequency increased significantly. Through regular cooperation with various media, featured reports, special editions, columns, and other means are utilized to interpret policy, eliminate doubt and confusion, and therefore effectively deliver scientific ideas.

Within the concept of coordinated and joint efforts, many ministries and departments jointly organized food safety awareness week activities. In 2013, 120 000 supervision staff, more than 4000 experts and scholars, and 35 million employees participated in activities. Hundreds of media issued nearly 20 000 news reports and over 300 000 micro-blogging topics. These activities created a good atmosphere in which the whole of society cares about, supports, and participates in food safety. According to incomplete statistics, in recent years, government departments, research institutions, societies, associations, and other organizations have organized 205 000 propaganda activities covering a variety of subjects and provided 110 million copies of various types of scientific brochure. It is estimated that more than 100 million people participated in such activities [12].

All local government departments work closely and practically cooperate with the media. They proactively accept media participation. Examples are inviting media reporters to join monitoring activities, participating in news topic planning, communicating before the implementation or issue of major policy and action, and organizing "role-playing" activities to promote mutual understanding. These actions not only meet the reporters' desire for news material, but also effectively improve the transparency of government food safety management, to deliver more accurate food safety information to the public.

19.7 The Current Situation of Food Safety Risk Communication in China

19.7.1 The Government Risk Communication System is Gradually Developing

Through several years of practical effort, risk communication has been gradually developed in the direction of institutionalization. The government is encouraging the inclusion of risk communication in 13 five-year plans. Risk communication of the "food safety regulatory system"-related provisions will be gradually integrated in newly a revised "Food Safety Law" and other government departments regulations [13]. An example is, "Beyond county level people's government, food and drug administration departments and other relevant departments, food safety risk assessment expert committee and its technical institutes, should communicate food safety risk assessment information and food safety supervision and management information to food processors, food inspection agency, certification bodies, industry associations, consumer associations and news media in scientific, objective, timely, and open manner."

Risk management covers the whole process from farm to table. Risk communication is also part of this process. Food-safety-relevant government departments are gradually improving communication, coordination, and links by establishing special task forces, signing cooperation memorandums, and appointing coordinators. An example is the China Food and Drug Administration establishing a risk communication mechanism with national and provincial food and drug supervision departments and relevant technical institutions. They have set up a dedicated electronic communication platform and have formed a risk communication working system.

At the same time, other government departments have gradually improved liaison mechanisms with industry associations via the appointment of coordinators and the establishment of an online task force. Government regulator think tanks are equipped through the development of a food safety expert database and a risk communication expert group. One example is the Health and Family Planning Department and food- and drug-relevant departments establishing food safety risk communication expert groups, which have created a think tank composed of experts from multiple fields with multi-disciplinary knowledge [14]. According to relevant departments, bureaus, and local food and drug departments, the China Food and Drug Administration have also chosen food safety risk warning experts and assembled a risk warning technical support group with food safety and statistics experts.

To further promote the development of risk communication system and capacity, the National Food Safety Risk Assessment Center assists the China Food and Drug Administration and Health and Family Planning Commission with developing risk communication working instructions and technical guidelines [15, 16]. Other government departments are also drafting formative documents on risk warning. The internal working mechanisms of each system are gradually becoming organized and improved upon. Based on accumulated practical experience, the China Food and Drug Administration is organizing experts from different fields to systematically organize typical national and regional experiences and practices, and prepare risk communication-related technical documents and training materials. The risk communication training system is gradually improving and will be used to guide food safety regulators to perform relevant work. The China Food and Drug Administration and Health and Family Planning Commission have completed risk warning communication theory and practice training for system-wide administration and responsible technical personnel. A total of more than 700 people received training. Practical exercises are highlights of this training and have improved training effectiveness.

Food safety-related news propaganda is developing in the direction of institutionalization and standardization. For example, the China Food and Drug Administration is strengthening the review and management of its responsible newspapers, as well as strengthening the management of reporter certificates and correspondent stations. Meanwhile, the China Food and Drug Administration are actively preparing for the establishment of public information centers and media groups order to promote long-term development of food safety news and media. The General Administration of Quality Supervision, Inspection and Quarantine of the People's Republic of China (AQSIQ) encourages its local offices to develop an information gathering network, which closely tracks the information related to the import and export of food and guides public opinion in a timely manner. Through the organization of training courses for spokesmen and media reporters, and the development of corresponding reporter contact lists, each government department improves government news releases, which enhances the professionalism of media reporters, while developing a group of news propaganda professionals with high ethics and expertise.

19.7.2 Government Food Safety Risk Communication has Intensified

To rebuild the credibility of relevant organizations, government departments have focused on the disclosure of government information and have actively promoted transparency of regulatory information. The China Food and Drug Administration have developed a procedure for releasing food safety monitoring and sampling information. These standardize the way local governments release this type of information. This procedure, which has officially been implemented, sets expectations on principals of information release, responsibility, content, procedure, frequency, method, and other perspectives. It has helped to establish a unified regulatory authority for the overall food and drug administrative department. Besides general regulatory information, the China Food and Drug Administration is also gradually developing food safety risk warning systems or consumer alert systems. The China Food and Drug Administration has released consumer alerts on poisoning prevention when consuming wild mushrooms, food safety in the summer, and when consuming dumplings and moon cakes. The China Food and Drug Administration has guided some coastal provinces to promptly release risk warning information on shellfish toxins, and has issued a risk warning on the prevention of Nassacrius poisoning.

Each government department proactively responds to food safety hot topics. Meanwhile, scientific explanations of topics that are likely to cause social concern are also given in advance. An example is the way the Health and Family Planning Department integrates and simplifies its work with standards and further enhances the readability of information on a transparent basis. It strengthens initiation that guides public opinion by interpreting scientific rationales in advance. The China Food and Drug Administration set up a food safety risk communication and warning column on an official website, including two subsections: food safety alerts for consumers and risk interpretation, the latter of which is also added to newspapers and magazines. Information publishing and policy interpretation are launched simultaneously, interpretation tips follow the publishing of scientific information, interpreting articles are published along with important information, and press releases and expert interpretation are provided when major events and policy releases occur, to interpret policies and answer questions in a multi-angle, comprehensive, orderly, and effective manner.

The China Food and Drug Administration continues to escalate the publishing of sampling results and risk monitoring information. For example, moon cake and dumpling monitoring and sampling information is particularly published, and the publishing frequency of supervision and sampling information is gradually being increased. Not only is relevant information made public, but situations, problems, and recommendations identified during sampling is also communicated with key industry associations and company representatives, to guide the industry to further enhance quality and safety to the next level. Ways and methods of monitoring and announcing sampling results also continue to improve. Initially only substandard products were reported, which does not comprehensively reveal the food safety situation to the public. Later on, information on in-specification and out-of-specification products was released at the same time, then out-of-specification products were also further divided into products that may affect health and will not affect health (e.g. mislabeling).

Each sector is also actively involved in media communication and agenda setting to guide public opinion. An example of this is a series report on managing table contamination issues in Fujian Province, which received wide attention from various social segments. Series reports on regulatory reform, which is jointly planned by the China Food and Drug Administration and other media such as Southern Weekend, have become an important driving force of public opinion. Cooperation between government departments and CCTV, Xinhua Net, and other mainstream media continue to develop. They proactively respond to social concerns such as the Husi meat scandal and Taiwan illegal cooking oil which were revealed by the “3.15” party. In 2014, major media reports on the China Food and Drug Administration accumulated in number to more than 50 000 of which 431 were broadcast by CCTV and 10 were news network broadcasts.

Government regulators have begun to pay attention to the utilization of new media to build their own journalism brands. For example, they actively promote the development of official micro-blogging; currently the official “China Food and Drug Administration” micro-blogging account has more than five million followers on the Internet and has released a total of nearly 400 micro-blogs. In 2014, the official “China Food and Drug Administration” micro-blogging account ranked fourth and first in the Sina’s “Top ten ministries and government micro-blog accounts” and “Top ten medical and health micro-blog accounts”, respectively. In addition to the official micro-blog account, all departments have joined the official WeChat platform. The China Food and Drug Administration have developed a mobile application “Food and Drug News” which proactively delivers official information on food and drug safety to readers.

19.7.3 The Participation of Various Society Segments Continues to Improve

The participation of all segments of society is the only way to achieve food safety governance. Risk communication plays an important role, as activities echoing the theme of “National Food Safety Awareness Week” intensively expressed the participation of society in food safety. Sixteen ministries at the central committee level organized and carried out a number of activities around the theme day. A total of 670 000 regulatory staff, over 7500 experts and scholars, and more than 2200 million food industry employees, young students, and media workers were involved in these activities, which reached 2.6 million people.

To keep abreast of misunderstandings and concerns of the public, and to further guide the public to recognize food safety issues, online knowledge competitions have been organized. By holding “old flavor, old story, and old brand –the power of adherence to integrity” activities, a historical heritage and integrity business philosophy of food culture has been presented from multiple perspectives, and traditional Chinese virtues of morality and trustworthiness have been promoted. This activity drew wide attention from society. Communication capability is collaboratively enhanced by organizing new media skills open courses, which set up a communication bridge between the media, experts, and regulators.

The CCTV and other media are planning the production of a series of food safety science educational films, which include the voices of experts, regulatory authorities, business representatives, and consumers, to show the whole picture of food safety. The China Economic Net has organized food safety-related volunteer activities on college campuses, and science education workers and volunteers have visited primary and secondary schools to enhance the food safety awareness of students and parents by explaining and answering questions. They also launched a “citizen journalism” (collecting, disseminating, and analyzing of information by the general public) food safety training camp, which enables food safety experts and opinion leaders to communicate and share opinions.

Regulatory authorities pay special attention to inviting scientific communities to engage in risk communication research and practices from multiple perspectives. For example, a food and drug safety news media scholar youth league has been established for the long-term development of food and drug propaganda. This youth league invites young scholars who study journalism and communication from scientific research institutions to jointly plan, research, and implement food and drug safety news communication activities for youth groups. The China Food and Drug Administration and Tsinghua University jointly built a food and drug safety visualization propagation base to enrich means of communication by designing comics, illustrated information, and video clips to adapt to the public reading habits of visualization, fragmentation, and entertainment.

The participation of the food industry and companies in risk communication is growing, such as the Chain Store Operations Association, which launched the “Food Safety in Grocery Stores” activity. They developed uniform food safety brochures and spread the information by placing brochures on shelf labels and paper tray mats. Other chain store operators also organized knowledge contests, video broadcasts, distributed brochures, and various other science activities in their own stores. Local businesses and the Science and Technology Association worked together and built a food safety science education campus to help local consumers understand the modern food industry. Internet-based online store operations are also actively involved. They integrate food safety knowledge and their product information on their web site's front page. In addition, the food industry is also actively collecting food safety risk information to provide timely feedback and a useful reference for risk prevention and control to regulators.

China also values international cooperation and communication in the field of risk communication, focusing on learning advanced experiences. China's government cooperated with the World Health Organization (WHO), the World Bank, the European Union, the International Food Information Society, Harvard University, Yale University, and the Global Food Safety Initiative (GFSI) by holding seminars, forums, training and other activities to promote government departments, consumers, society business and other interest parties to achieve agreement.

19.8 Future Perspectives for Risk Communication

19.8.1 Official Organization Communication Shifts from Reactive Responding to Proactive Communication

As the popularity of public opinion reduced and public panic gradually subsided, the main content of government food safety risk communication shifted from "crisis management" to proactively communicating scientific knowledge. Government and research institutions will gradually shift from "waiting for media inquiries" to "informing the media." The Traditional Government Information Office will gradually transit from publishing information towards establishing public and media relations.

The risk communication-related system will gradually improve by strengthening the development of professional staff, standardizing staff training system, organizing regular training for press spokespeople, and cultivating a team of risk communication experts through specialized training materials. Developing a group of experts, scholars, opinion leaders, and key staff who have both scientific knowledge and communication skills will drive risk communication.

Regulatory information will be published in a more proactive manner and gradually build an information release platform for the public and the media. Information dissemination models will be more scientific and complete. The release of results information will lead to the release of process information, and therefore fulfill the openness and transparency of food safety events. The effect of "National Food Safety Awareness Week" will continue to strengthen and become a learning and sharing platform for all departments and stakeholders. These measures will gradually reshape the public credibility of the regulatory authorities and become a stabilizer in future when a food safety crisis takes place.

The link between the government regulatory agency and the media will continue to be strengthened. Regular public press and occasional featured reports will be the main line, at the same time, conference, briefing, live interviews, group interviews, TV columns, visual communication, and other publishing methods will be adopted as necessary. Social marketing concepts will be gradually accepted by government departments, traditional media and new media, presenting a growing trend of convergence. Distribution channels will gradually transition from traditional media to a combination of microblogging, WeChat, and smart phone applications, aiming to enhance autonomy and interactive communication. On the basis of public opinion estimation, a public opinion response mechanism will be set up in a prompt manner. Early intervention capacity will be increased gradually. Full use of the media, experts, and other third parties and platforms, and active involvement in agenda-setting will take the initiative to guide public opinion.

Food science academia will put more emphasis on the transfer from scientific research to public awareness, from scientific knowledge to public common sense. There is a likelihood that dedicated funds from major research projects will be used for science communication. College public health or food-related majors should include science communication in their curriculum design. Food safety education will be gradually extended to high school, middle school, elementary school, and kindergarten.

19.8.2 Companies and Industry Will Become the Driving Force in Risk Communication

In that time, companies will not continue to be bullied by public opinion. The industry association will gradually become a communication bridge between companies and society. Industry organizations that lack the capability to spread public opinion and influence will gradually be abandoned by companies. Instead, companies will gradually step out of the brutal competition within the industry and form a food safety alliance to generate a win-win situation throughout the industrial chain. Public opinion attacks caused by unfair competition will be gradually reduced.

The industry and companies will come to realize that the spread of scientific knowledge and marketing should be given the same priority and become part of corporate social responsibility. Some powerful companies within the industry will invest more resources in science communication. Social resource investment driven by them will exceed that from government and will become the main force in risk communication.

19.8.3 Public Opinion Will Return to Scientific Rationality

After several consecutive years of high-density bombing of rumors, the media will gradually gain a “self-reflection function.” Media reports will become more rational, and the phenomenon that the mainstream media follows speculation will gradually disappear. Some among the powerful major media will ensure the scientific nature and objectiveness of its reports by hiring subject matter experts. Reports of food safety will gradually become professional. Some of the media that focus in this area will form a nucleus in the public opinion field.

There will be a trend of diversification in public opinions, but their questions and challenges will push the overall transparency of regulatory information and promote scientific risk management, then promote more conversations between government and society. The number of “independent third party evaluations” will increase and those third parties will eventually form several brands with credibility and influence. Their survival depends on the speed of the government in rebuilding its credibility, which is actually a battle for credibility.

Human rights lawyers and professionals who fight against fake products will still be an important force for public opinion in the near future. Although persistent lawyers have received positive, negative, and mixed comments, they will push the improvement of laws, regulations, policies, and standards, and promote government information to have a deeper and more open attitude. They are forcing companies to pay more attention to the health and appeal of consumers through public interest litigation and class actions.

19.8.4 The Consumer Food Safety Concept Has Gradually Been Shaped

With the development of the national economy and the gradual improvement of the social security system, consumer wealth will gradually increase. Food fraud issues will reduce as the credibility system gradually improves, the public's expectations of food safety will shift from "zero risk" to "controllable risk," and there will be a food shift from "inexpensive" to "value".

Future negative news on food safety will gradually return to the farm from the table, and will trace back to agricultural production or even more upstream to environmental pollution from the food production chain. The public will come to understand the length and complexity of food safety issues, and promote the entire food safety management system through the joint development of public opinion.

References

1 FAO/WHO. FAO Food and Nutrition Paper 70: The Application of Risk Communication to Food Standards and Safety matters, Report of the Joint FAO/WHO Expert Consultation[EB/OL]. (1998-02-6) [2014-06-30]. http://www.fao.org/docrep/005/x1271e/x1271e00.htm (accessed November 2016).

2 FAO/WHO. FAO Food And Nutrition Paper 87: Food Safety Risk Analysis, A Guide for National Food Safety Authorities[EB/OL]. (2006-11-1) [2015-06-30]. ftp://ftp.fao.org/docrep/fao/009/a0822e/a0822e.pdf (accessed November 2016).

3 FAO/WHO. *Food Safety Risk Analysis: A Guide for National Food Safety Authorities.* Translated by Yongxiang Fan, Junshi Chen. Beijing: People's Medical Publishing House, 2008:50.

4 China Government Portal. China Has Established First National Food Safety Risk Assessment Expert Committee. [EB/OL]. (2009-2-18) [2015-6-30]. http://www.gov.cn/jrzg/2009-12/08/content_1482962.htm (accessed November 2016).

5 Junshi Chen. What Can We Learn from the 2008 Melamine Crisis in China? *Biomedical and Environment Sciences*, 2009(22):109–111.

6 China Food and Drug Administration. Food and Drug Safety News Communication Young Scholars' Union Initiative: Stay on Truth, Promoting Participation from All Segments of Society. [EB/OL]. (2014-04-28) [2015-06-30]. http://www.sda.gov.cn/WS01/CL0050/98854.html (accessed November 2016).

7 China Economy. China Food Information Center Has Been Established in Beijing. [EB/OL]. (2014-10-14) [2015-06-30]. http://www.ce.cn/cysc/sp/info/201410/24/t20141024_3772498.shtml (accessed November 2016).

8 Southern Weekly. Food Safety Law Going Forward and Backward. [EB/OL]. (2013-11-28) [2015-06-30]. http://www.infzm.com/topic/jianyanzhe201301.shtml (accessed November 2016).

9 Xinhua News. Key 30 of China Food Safety Forum Has Been Established. [EB/OL]. (2014-01-17) [2015-06-30]. http://news.xinhuanet.com/expo/2014-01/17/c_126021797.htm (accessed November 2016).

10 China Food Safety Network. Call for Papers: Food Safety Risk Communication. [EB/OL]. (2014-10-29) [2015-06-30]. http://www.cfsn.cn/zhuanti/2014-10/29/content_240525.htm (accessed November 2016).

11 China National Center for Food Safety Risk Assessment. 2015 International Food Safety Forum Held in Beijing, CFSA Experts Awarded the Honor. [EB/OL]. (2015-04-27) [2015-06-30]. http://www.cfsa.net.cn/Article/News.aspx?id=7D3D497DC716469AD1829C4EDAC8B2BC8AE5D37F30B16AEF (accessed November 2016).

12 Food Safety Committee of the State Council. Internal Reference [in Chinese].

13 Xinhua News. Food Safety Law of the People's Republic of China. [EB/OL]. (2015-04-25) [2015-06-30]. http://news.xinhuanet.com/2015-04/25/c_127731151.htm (accessed November 2016).

14 China Food and Drug Administration. Wenqi Guo Attended First Plenary Session of China Food and Drug Administration Food Safety Risk Communication Panel. [EB/OL] (2014-09-29) [2015-06-30]. http://www.sda.gov.cn/WS01/CL0048/107206.html (accessed November 2016).

15 National Health and Family Planning Commission. Food Safety Risk Communication Working Instruction and Technical Guidelines. [EB/OL] (2014-02-17) [2015-06-30]. http://www.nhfpc.gov.cn/sps/s7885/201402/c73f0cf331234ef285c190fd1df5b915.shtml (accessed November 2016).

16 China Food Safety Law Network. China Food and Drug Administration Successfully Initiated the Composing of "Food Safety Risk Communication Working Instruction and Technical Guidelines". [EB/OL] (2014-11-21) [2015-06-30]. http://www.foodlaw.cn/lawhtml/zgspaqfzyjzx/zxdt/6860.shtml (accessed November 2016).

20

Consumer Knowledge, Attitude and Behavior Toward Food Safety

Li Bai[1] *and Shunlong Gong*[2]

[1] *College of Biological and Agricultural Engineering, Jilin University, China*
[2] *School of Management, Jilin University, China*

20.1 Introduction

Food safety currently represents a genuine national crisis that emerged during the socio-economic development of China. To assure the safety of food, the total food chain, which includes four links – farmers, manufacturers, retailers (including catering retailers), and consumers, have to be involved [1]. In recent years, the Chinese government has made great efforts to ensure the safety of the food supply chain such as issuing the Food Safety Law of the People's Republic of China in 2009 and popularizing traceable foods, but it has not been concerned about the final link – the consumers.

Consumers are the final link in the food chain in assuring safe food consumption and prevention of illness since they not only purchase products, but also process and provide food for themselves and others [2]. In developed countries like Canada, a number of organizations (the Public Health Agency of Canada, Health Canada, and Canadian Food Inspection Agency) promote safe food purchase and handling, most notably the Canadian Partnership for Consumer Food Safety Education's Fight BAC Program [3]. Designing educational programs targeted at improving food safety knowledge and behavior should be based on a true understanding of the actual level of relevant audience [4]. However, consumer knowledge, attitude, and behavior toward food safety are relatively understudied in China.

Safe food purchase and proper food handling are both important for consumers to be assured of the safety of food consumption. Since many food products bought by consumers are frequently contaminated with naturally occurring pathogenic microorganisms, there is a need for consumers to implement safe procedures during routine handling, preparation, and storage of food [2]. Consumers can consume safe food only if they have purchased safe food and prepared it by following recommended rules or procedures.

It was reported that during the period from 1999 to early 2010, a total of 2387 food poisoning outbreaks occurred in mainland China and 24.4% of them were caused by food consumed at home, followed by 23.4% in restaurants, 15.2% in school cafeterias, 12.4% in company cafeterias, and 9.6% at rural family banquets [5]. A recent government

Food Safety in China: Science, Technology, Management and Regulation, First Edition.
Edited by Joseph J. Jen and Junshi Chen.

bulletin indicated that 50.6% of the reported food poisoning cases and 85.5% of the deaths were attributed to food that was prepared at home during 2014 [6]. It also suggested that the “private home is the location where most food-borne cases occur”.

To date there is no single summary document regarding knowledge, attitude, and behavior toward food safety of Chinese consumers. This chapter will compile all relevant literature including published and peer-reviewed papers. The objectives of this chapter are: (a) to demonstrate knowledge, attitude, and behavior toward aspects of safe food purchasing and food handling, and (b) to make recommendations for future research by comparison with studies from other countries.

20.2 Materials and Methods

A systematic electronic search of published peer-reviewed Chinese and English literature was conducted. Relevant research in the field of consumer food safety was located. The Chinese language papers were selected from the CNKI (China National Knowledge Infrastructure) database. CNKI is the biggest Chinese literature database, including Chinese academic journal articles, doctoral and master’s dissertations, conference articles, and other types of documents. The English language papers were mainly selected from the ISI Web of Knowledge and Google Scholar.

The search algorithm was composed of combinations of consumer terms (“consumer,” “public,” “home,” “domestic,” “household,” “food-handler/food handler,” “cook”), food safety terms (“food safety,” “food-handling/food handling,” “food preparation,” “safe handling/safe-handling,” “safe food,” “green food,” “organic food,” “traceable food”) and behavior terms (“knowledge,” “awareness,” “behavior,” “practice,” “perception,” “belief,” “attitude”). The search was carried out in Chinese and English and the timeframe was limited to 2000–2015.

Studies selected for review were those that examined consumers’ knowledge, attitude, and/or behavior related to food purchase and food handling and/or food preparation. The knowledge category was comprised of: consumer general knowledge about selecting safe food; consumer general knowledge about handling, storing, and preparing it within the home environment; the sources of food safety knowledge; and “high-risk” groups with the poorest knowledge. The attitude category was comprised of: consumer perception and confidence in food safety, consumer attitude toward safe food, particularly organic food and traceable food, and consumer willingness to pay for safe food. The behavior category was comprised of: consumer behavior toward the purchase of safe food, recovery of food purchase after food scandals, consumer behavior of handling, preparing, and storing food at home, factors influencing consumer food safety behavior; and “high-risk” groups with the poorest behavior.

20.3 Consumer Perception and Confidence in Food Safety

Food safety incidents in China have varied from microbiological problems to melamine in milk powder, clenbuterol in pork, Sudan dyes in duck eggs, and plasticizer in beverages. The rise in contamination and frequent food safety incidents has significantly driven Chinese consumers to be more concerned about the safety of food, particularly in regard to dairy products, eroded consumer confidence in food safety, and decreased consumer trust in manufacturers, retailers, and supervisory agencies of food [7–10]. According to a national survey conducted by *Xiaokang* magazine in 2012, food safety continues to be ranked as the top issue, with 65.8% of respondents indicating a high level of concern about it [11]. More than 70% of the respondents surveyed at "Nongmao" markets (traditional agri-product markets) in the Chinese capital of Beijing also indicated a high level of concern about food safety in China [12].

Most Chinese consumers are not satisfied with the current food safety situation and lack of trust in food safety in China. Only 53.1% of Chinese consumers consider the food supplied in the Chinese market to be "safe" or "very safe" in 2003 [13]. As much as 36% of the respondents in the Jiangsu province (southeast China) were strongly dissatisfied with the food safety situation within the province in 2009 [14]. Slightly over one-third (35.3%) of Beijing's consumers considered the food supplied in the Chinese market as safe, 14% considered it not safe, and up to 50.7% held the opinion that "I cannot tell at all" [12]. A 2014 study revealed that 78.64% of the 1573 respondents described the food safety situation in China as "grim" and 64.97% lacked confidence in food safety [15]. Also, many consumers lack trust in certified food like organic food, although they admit the necessity for food safety certification systems implemented by food safety regulation agencies [16]. A 2016 study suggested that very poor families living in smaller cities were among those most concerned about food safety in urban China [17].

In 2004, when purchasing food, the Chinese consumer mainly focused on the date of manufacture and shelf life, chemical residuals of pesticides and veterinary drugs, and the abuse of food additives [13] over concerns relating to food safety. In 2011, they were more concerned about "if the product has passed its sell-by date" and "if the package has damaged," but less about "if the product contains artificial additives" and "if the product is officially certified green food" [18]. While the study in 2014 reported that price is still one of the main factors affecting consumer food choice, there were other key factors such as date of production, freshness, reputation of retailer, food safety labels, and information about fertilizers or pesticides. Sale location and brand also significantly influence consumer purchase behavior [15]. A 2015 study show that, when using a stated preference method to collect data, "safety" was chosen as their first consideration when purchasing pork hindquarters, whereas choice experiments revealed that consumers chose "appearance" as their first consideration [19]. Another 2015 study reported that urban consumers in Nanjing city (southeast of China) ranked counterfeit foods as the No. 1 safety threat, chemical contamination as No. 2, and "polluted" foods as No. 3 – all of which are rare in most developed nations [20].

With the rise in income, Chinese urban consumers not only consume more milk, but also demand more safety, and the demand from elderly consumers was negatively affected by higher price [21]. Brand and shopping location were ranked as the top two indicators when purchasing liquid milk, while price, package, and certification label were relatively unimportant [22]. The China melamine in milk powder scandal in 2008 has significantly damaged consumer confidence not only in the dairy industry, but also in China's total food supply chain, since many famous food producers were involved in the scandal. The scandal has raised increasing concerns from the international audience. In such a case, many studies were conducted to explore the influence of scandal on consumer food risk perception, confidence in food safety, trust in producers and supervisory agencies, and food purchase behavior [23, 24]. A survey in September

2009 – one year after the scandal – revealed that families with young children in Hohhot (north China) had reduced milk consumption by at least one-third and 39% of the survey families had stopped consuming milk. In addition, the families that reduced consumption had higher concern for food safety issues than other households that did not [25]. The decrease in consumption among low-income groups was much more obvious after the scandal [26]. As of 2012, dairy consumption had not totally recovered [27]. China's consumers indicated that they usually took three measures, "often searching related information," "resorting to food retailers," and "choosing trustworthy brands" to assure of safe purchase of dairy products [28]. In addition, Chinese urban residents who usually purchased milk in supermarkets were less likely to pay a premium for dairy products with enhanced safety because they trusted in supermarkets and considered everything sold in them safe [21].

The Chinese consumer confidence in food safety is significantly determined by their assessment of the safety of food, their trust in food suppliers, retailers, and supervision agencies, and their personal traits of anxiety [29, 30]. Based on a unique data set collected from 11 cities in China in 2002 and 2003, Qiu concluded that in urban China, consumer acceptance of genetically modified foods (GMF) was high and positively affected by their trust in government. This would lead to serious underestimation of the influence of consumer trust in government if failing to consider its endogeneity [31]. Similarly, "consumer trust in supervisory agencies" was found to be an important factor that influenced their trust in food safety [32]. In addition, "trust in manufacturers" and "trust in retailers" were found to be directly and positively related to consumer food safety perceptions, but "trust in farmers" had no direct relation [33]. A survey among 862 consumers from the Jiangsu province (southeast China) revealed that Chinese consumers considered that farmers were relatively much more trustworthy, while manufactures and catering services were the most worthy of no trust. Media reports were much more trustworthy than information from the government [34]. The Chinese consumers' high ranking of counterfeit food as a threat offers hope for easing the crisis of confidence in Chinese food and that trust in the food system might be restored if increased regulation and prosecution leads to reduced counterfeit branding and increased transparency of information from both government and expert sources [20].

Although studies analyzing the influence of media attention or coverage of consumer confidence in the safety of the Chinese food system are still scarce, media reports in China have played a more important role in consumer risk perception and confidence in food safety. An example is the risk perception of the safety of genetically modified food (GMF). The percentage of Chinese urban consumers who perceived GMF as unsafe for consumption increased by more than 30% during the period from 2002–2012 although approximately half of the consumers still did not have an opinion on the issue. The major shifts occurred after 2010 and are attributed to the increasing influence of negative media reports on GM technology in recent years [35]. Online information will generally be an effective conduit for food-related information for younger, more educated, and higher-income residents [20]. Furthermore, in recent years, the media (such as micro-blogs) have drawn increasing attention to their role by exposing food safety scandals in China. The media has greatly increased dissemination of the voices of "opinion leaders" and triggered large-scale communication of food safety messages to the public. Therefore, in this seriously asymmetric information situation between the public and food manufacturers, food safety scandals revealed by the media can easily be noticed by consumers and further affect their risk perception and purchase behavior [36].

Finally, it should be further pointed out that much of the Chinese consumer concern and perception about food safety is not based on correct information. Add to that the horror stories, most of them having been exaggerated, about the poor quality of food production, preparation, and counterfeiting, which are unending in the Chinese media and a vivid report leaves the consumers increasingly distrustful of everyone involved and unsure if anyone is telling the truth [37]. Actually, widespread concerns over food safety have arisen partly from the illegal use of food additives and contaminants. Chinese consumers fear that domestic producers add dangerous chemicals to food [38], leading to social distrust of the food industry and the regulatory system. However, it should also be pointed out that a large number of consumers consider any food additives unsafe or dangerous, even if the additives are officially permitted by the government [39]. Furthermore, many Chinese consumers mistake non-food materials for food additives. A survey of 3531 consumers in seven Chinese provinces revealed that 72.5% of the respondents mistook melamine as a kind of food additive [40]. That might partly explain why China has been hit by a wave of food additive scares after the melamine in milk powder scandal in 2008.

Another misunderstanding is of fake or counterfeit food products [37], which are a big deal in many places in China. But, are all counterfeit food products unsafe? The answer to this question is “no” because only those that will cause harm to the consumer are unsafe. Unfortunately, a majority of Chinese consumers provide a positive answer to the question, which greatly enlarges the numbers of unsafe foods [41]. Compared with food additives, pesticides and drugs, and counterfeit brands, which attract unusual attention from Chinese consumers, food-borne illness has become the most serious food safety problem in China [42]. Unfortunately, save for some experts in China, few Chinese express lower concerns about food-borne illness or consider it a serious food safety problem [43]. The mismatch may be due to the fact that, while it is relatively easy for consumers to link a health problem (such as acute diarrhea) to infections resulting from the consumption of contaminated food, it is unlikely for them to link chronic health conditions with food tainted with toxic chemicals. Therefore, many consumers underestimate the severity of food-borne illness due to under-reporting and the difficulty of establishing causal relationships between food contamination and illness or death [44]. Another reason is that communication by regulatory agencies is weak and provides little information about food-borne illness and safe food handling rules to consumers. By comparison, media dissemination of misleading and sensational news about the harm of using food additives, pesticides, and fertilizers is widespread [42].

20.4 Consumer Knowledge, Attitude and Behavior Toward Safe Food Purchase

Many Chinese consumers usually take two measures, purchasing safe food and handling food in the right way, such as cleaning it with hot water or boiling it, to assure the safety of the food they consume. Many Chinese consumers choose food with quality labels like “China Famous Trade Mark”, with food safety labels like organic certification, or just based on their own judgement of the food by the appearance [45]. A survey in

Beijing revealed that 76% of the respondents had purchased labeled organic, green, or hazard-free vegetables more than once and 85% of them had taken self-protective measures like peeling or cleaning food with hot water during the past month [45].

20.4.1 Consumer Willingness to Pay for Food Safety

Most studies revealed that Chinese consumers have a high willingness to pay (WTP) for safe food. The mean WTP for vegetables with lower pesticide residues is 5.36 RMB per kilogram, equivalent to an increase of 335% over the regular price (1.60 RMB) for common vegetables [46]. A choice experiment among 843 consumers in the Shandong province (central China) in 2014 revealed that consumer WTP for a food safety certification label, a traceability label, and a brand were all significant. A complementary relation between food safety certification label and traceability label, a complementary relation between traceability label and brand, and a substitutable relation between food safety certification label and brand were found [47]. Another study, which was also based on the choice experiment method, indicated that Chinese consumers were willing to pay an average premium of 3.92 RMB for government-certified safe food, an average premium of 2.36RMB for well-known brands, and 1.80 RMB for a guarantee from the livestock farm, but their premium for third-party certified safe food was negative (an average of −0.24 RMB) [48]. In addition, a survey among Beijing consumers indicated that after receiving information on HACCP, nearly all respondents were willing to pay a modest price premium for HACCP-certified food [49].

Based on a survey among 416 consumers in the city of Shanghai (southeast China), demographic characteristics such as gender, age, marriage, income, and family scale were found to significantly affect consumer willingness to pay a premium price for products with certification regarding enhanced food safety [50]. In addition, Chinese consumers' willingness to pay for food safety is retail channel invariant. Although consumer preferences for animal welfare attributes were found, willingness to pay for animal welfare was significantly lower than for other food safety attributes [51]. However, the Chinese consumers' WTP for safe food was not consistent with their actual purchase behavior and the main reason for the inconsistency was that many consumers do not consider manufacturers and administration agencies to be looking out for them or producing and selling safe food products, and therefore consider "all food is almost the same in quality and safety" [52]. Similarly, the most recent study suggested that the poorest households are most concerned about food safety, also being those most exposed to risk given their budget constraints. It might explain why high sensitivity toward food security is not matched by a high willingness to pay a premium price [53].

Labels bearing the country of origin are also an important basis for consumer food decisions. Chinese consumers had a positive perception of US pork. Age, shopping location, and food safety concerns significantly influenced their willingness to pay for US pork [54]. A study reported that consumer WTP for infant milk formula (IMF) with an American or European organic certification label was higher than IMF with a Chinese label. Moreover, consumer knowledge of organic food and food safety risk perception had an impact on their WTP [55]. However, Wang reported in 2011 that the label of country of origin on raw meat packaging strengthened consumer confidence in the safety of the meat, but had less effect on their WTP, while a traceability label on the package increased both consumer confidence in the safety and their WTP [7].

In recent years, researchers have focused on the Chinese consumer purchase behavior of traceable food. To date, there are a few traceable foods in the Chinese market. Therefore, most studies mainly focused on the WTP and purchase intention for traceable food. In general, the knowledge of Chinese consumers about the connotation of traceable food is very limited and their willingness to pay a price premium for certified traceable food is also limited. A study in 2009 reported that more that 40% of 566 respondents had never heard of traceable food. Among the respondents who knew of traceable food, their knowledge of and WTP for traceable food was limited and significantly determined by the price of the traceable food, their confidence in food safety, their income level, and their age [56]. In 2010, Xu and Wu reported that only 37% of the respondents had heard of the concept of food traceability and 32% of those that had purchased certified traceable food were unwilling to pay a price premium. In addition, trust in food safety, knowledge about food traceability, gender, age, educational level, and income were main determinants of WTP [14]. As reported by Wu, Chinese consumers' willingness to pay a premium price for certified traceable food is limited and affected by income, education, perception of and attitudes toward food traceability systems, as well as the degree of concern over food safety. However, the effects of these factors on the actual premium a consumer is willing to pay are quite different. Conditional on the consumer being willing to pay a positive price premium, income level and the degree of concern over food safety are the only two factors that have significant effects on the actual premium consumers are willing to pay [57].

Pork was the first traceable food in the Chinese market. Furthermore, pork consumption accounted for more than 50% of its domestic meat consumption. Chinese consumers are willing to pay a premium for safety information about traceable pork hindquarters, particularly government-certified pork hindquarters since traceable food certified by the government had a higher part-worth utility. Income was found to be a key factor influencing the part-worth utilities of traceable safety information and price [19]. In addition, the purchase of traceable pork was significantly affected by gender, self-evaluation of health, awareness of the traceability system, concern over food safety, and willingness-to-pay a price premium [58].

As for traceable dairy products, Bai reported that urban Chinese consumers have a strong desire for traceable milk, but their preference for traceable milk is significantly related to the associated certificate issuers. Their highest WTP goes to government-certificated traceable milk, followed by industry association-certificated milk and third-party-certificated milk [59].

20.4.2 Consumer Knowledge, Attitude and Purchase Behavior Toward Organic Food

The Chinese safe food market mainly consists of hazard-free food, green food, and organic food. These three kinds of food have been widely used in Chinese academic studies as representative of safe food. A great deal of research work discussed Chinese consumers' knowledge, attitude, and purchase intention and behavior toward the three kinds of safe food [60, 61]. Consumer attitudes and behavior toward safe food in Chinese research studies up to 2010 have previously been reviewed, providing a comprehensive overview of the literature that discussed consumer awareness and knowledge, attitudes, behavioral intentions, purchasing behavior, and determinants of the three kinds of safe food consumption in China [62]. Therefore, to avoid redundancy and considering how the safety of organic food from China has gained the world's attention from scholars to the public, while green food and hazard-free food are only produced and consumed within the Chinese market, this chapter incorporates some areas of that review and particularly reviews consumer knowledge, attitude, purchase intention, and behavior toward organic food.

Food safety issues in China make organics a profitable market. Sales of organic food in China have grown fast. In 2004, the total value of organic production in China was 2.2 billion RMB, with only 200 million RMB going to the domestic market. In 2008, the total value of organic production in China reached about 16 billion RMB (US$ 2.4 billion) with the domestic organic market reaching US$ 1.1 billion [63]. However, Chinese consumer knowledge of organic food is still quite low [61]. For example, less than one-quarter of the respondents in Dalian (northeast China) knew the connotations of organic food, and almost half of the samples totally confused organic food with green food [60]. Only 48% of the interviewees in the city of Beijing knew about organic food [62].

Chinese consumers identify organic food based on organic certification labels, packaging, or advertisements. In particular, the organic certification label is an important basis for consumers to identify organic food. Unfortunately, less than 10% of the consumers in the city of Guangzhou (south China) could identify organic labels [64], and only 20.4% of the respondents in the city of Xi'an (western China) could recognize organic pork labels [65]. However, another survey, conducted in the two cities of Nanjing (southeast China) and Shanghai (southeast China), revealed that a majority (74%) of consumers who knew about organic pork could recognize organic labels and knew it was officially certified [66].

The motivations for Chinese consumers to purchase organic food can be classified into two categories: altruistic motivation and individual motivation. Altruistic motivation is rooted in the characteristic that the production process of organic food is environmentally friendly and promotes the sustainable development of agriculture. The individual motivation is rooted in the characteristic of organic food that it is much safer, nourishing, and beneficial to health [67]. By now, individual motivation, rather than altruistic motivation, is the major motivation for Chinese consumers to purchase organic food [67]. About 90% of Chinese consumers choose organic food because it is much safer and more nutritious, and only a few consumers select organic food because it is environmentally friendly [68]. Although consumers with more concern about environmental pollution are inclined to have a more positive attitude and intention toward organic food, concern about environmental pollution may not significantly and directly affect their real purchase behavior, which is still determined by their consideration of the characteristics of organic food itself, such as safety and nutrition [69].

Among Chinese consumers that have positive perceptions and attitudes about organic food, not all have purchased it. A 2008 survey among 10,000 Nanjing consumers revealed that only 1.25% have purchased organic food [68]. A study in 2012 revealed that 59.2% of Chinese urban consumers have purchased organic food [70] and a 2013 study reported almost the same (57.6%) [71]. In addition, Wang and He also reported that although more than half of the respondents have positive perceptions about organic food, only 10% of them state a regular purchase [72].

The higher price and distrust of the production process of organic food and the organic label are major factors that cause the attitude–behavior gap or the intention–behavior gap [68–73]. Personal characteristics, such as income [70, 71], gender [71, 73], educational level [70], and marital status [73] significantly influenced consumer behavior in purchasing organic food. As for the factors influencing purchase intention, Yin reported that Chinese consumer purchase intentions toward organic food were strongly affected by income, degree of trust in organic food, acceptance of organic price, and concern about health, and were slightly affected by age, education level, and concern about environmental protection [74]. Zhou reported that the availability of positive information significantly affected the purchase intention of consumers in Nanjing City. The ratio of respondents that were willing to purchase organic pork increased by 20% after the surveyors provided them with detailed information about the production process and quality control of organic pork [13].

20.4.3 Recovery of Food Purchase After Food Scandals

Following a food scandal, the recovery of purchase is not always consistent with the risk perception of the food and the inconsistency is affected by consumer knowledge about the incident, consumer trust in government, consumer risk preference, personal income, and educational background [75, 76]. Consumer trust in information provided by the Chinese government significantly and positively influenced their purchase recovery of dairy products after the melamine scandal, which implies the essential role played by risk communication after food safety incidents [77]. Another study in 2015, which employed the frame of a dual-process model of defense, revealed that consumer purchase intentions dropped sharply in the short term after food safety accidents, which is determined by individual attitude and negative emotion, but not by trust in government agencies or in food enterprises. However, with development of the incident, their purchase intention may fluctuate and be directly influenced by enhanced supervision from government agencies and by the guarantee of food quality and safety from related enterprises [78]. While another study indicated that consumer trust in the government had a positive influence on their resumption of dairy product use after the melamine scandal, but trust in mass media had a negative influence, and the measures and information taken and published by food enterprises had no significant influence at all [75].

20.5 Home Food Safety and Consumer Knowledge, Attitude and Behavior

Compared to food purchase behavior, little attention has been paid to home food safety and consumer food handling and preparation, and therefore this field is relatively understudied in China.

20.5.1 Food-Borne Illnesses and Consumer Home Food Handling Behavior

In 24.4% of the 2387 incidents of food-borne illnesses that were reported by medical professionals in published journal papers during the 1999–2010 period in China, food was consumed at home, followed by restaurants (23.4%), school cafeterias (15.2%), company cafeterias (12.4%) and rural family banquets (9.6%) [5]. Of the incidents in which food was consumed at home, 265 deaths were found, occupying about 70% of the total deaths. Furthermore, 45.3% of the deaths were caused by man-made chemical hazards, 29.4% linked to poisonous mushroom, plant, and animal toxins, and 25.3% caused by deadly bacteria [5]. Since food contamination caused by bacteria has a lower mortality than poisonous mushroom and man-made chemical hazards, we can deduce that, in the home environment, the ratio of incidents caused by bacteria is surely higher than the above-mentioned 25.3%.

Because of different geographic positions, people's living standards, and eating habits, the outbreaks of food poisoning occurring at home and their causes are significantly different. From 2004 to 2012, of the 113 food poisoning incidents that occurred in a home environment in Sichuan province, 44 were caused by man-made chemical hazards, 37 were linked to poisonous mushroom, plant, and animal toxins, and 32 were caused by bacteria [79]. In addition, most of the deaths from food poisoning at home occurred in rural families, attributable to backward medical conditions, bad traffic, and lack of awareness of food hygiene, and a majority of them were caused by mushroom, plant, and animal toxins, and man-made chemical hazards [80, 81]. For example, of the 184 food poisoning incidents occurring in rural families of Zhejiang province (southeast of China), 49.5% were caused by bacteria. However, of the 24 deaths from the 184 incidents, 79.2% were caused by mushroom, plant, and animal toxin, and 20.8% were linked to man-made chemical hazards [82].

Food coming from home or with the home as the source of contamination was considered to be connected to 15.8% of total food poisoning incidents and accountable for 45.3% of the deaths, and unhygienic practice come out as one of the major factors in food poisoning in China [5]. During the past two decades in China, *Salmonella* and *Vibrio parahaemolyticus* have been the causes of most of the bacterial food poisoning outbreaks occurring at home [81, 82]. From 2004 to 2012, Salmonella caused most (23.2%) of the bacterial food poisoning occurring at home in the Sichuan province (southwest China) [79]. With people in Zhejiang (southeast China) and the Guangdong province (south China) prefering to consume seafood, particularly raw seafood, *Vibrio parahaemolyticus* is identified as the leading cause of bacterial food poisoning outbreaks at home [83]. The most common factor contributing to *Salmonella* and *Vibrio parahaemolyticus* contamination is cross-contamination, followed by improper cooking and improper storage [79, 84].

20.5.2 Consumer Knowledge, Attitude, and Behavior Regarding Home Food Handling

It seems that most Chinese consumers do not think they should shoulder the same responsibilities as the food manufactures and supervision agencies. Respondents in a survey of "Who should shoulder the major responsibilities to assure the safety of food" awarded a mean score of 4.69 to food manufactures, 4.64 to catering services, 4.56 to retailers, 4.50 to supervisory agencies, but only 3.37 to consumers [85]. A national survey of food handlers, conducted in 2012–2013, revealed that the respondents demonstrated a very low level of knowledge about home food safety and handling [86]. Out of 26 knowledge questions, correct answers given by different groups ranged from 7 to 11, with the mean score being 7.95 (knowledge scores from 0 to 26). Knowledge of food poisoning and personal hygiene are the two aspects that demonstrate the most consumer ignorance [86]. A survey among consumers in the city of Nanjing (southeast China) reported that, for 10 questions about home food safety knowledge, the rates of answering five questions correctly were all below 20% [87]. Another study found that food handlers in the city of Guangzhou (south China) also demonstrated very poor knowledge. Out of the 12 questions surveyed there, the median score was 5 (scores from 0 to 12) and knowledge scores were found to be positively related to behavior scores [88]. Teng reported that 44.0% of the 1030 respondents did not know the proper temperatures for refrigerators and freezers [85].

The meat handling practices of Chinese consumers involve serious food safety risks. A national survey revealed that all the respondents (n = 1393) had at least two violations of the 15 recommended practices, despite the fact that a single violation may potentially lead to food-borne illnesses. More than 60% of the 1393 respondents failed to thaw raw meat properly, 40.4% did not wash hands with detergent after raw meat preparation, 44.8% cleaned cutting boards in ways that allowed cross-contamination, and 81.9% did not put leftover meat into refrigerators immediately after meals [89]. More than half of the 1006 respondents from Guangzhou failed to wash hands adequately or at all, 74.8% used and cleaned cutting boards and tools in ways that allowed cross-contamination, 41.7% did not reheat food to a high enough temperature, and 51.5% could not implement safe procedures to thaw frozen food [88]. Bai designed nine scales to investigate key behaviors of home food handling and preparation and, for each scale, the maximum possible score each respondent could obtain was five. The scores for the nine scales were 2.85 (use of plastic wrap), 3.04 (thawing), 3.04 (separating), 3.10 (storing), 3.21 (cleaning of fridge), 3.27 (leftover handling), 3.34 (temperature of fridge), and 3.67 (heating) [90]. Teng reported that 63.2% of the 1030 respondents failed to thaw meat in a safe way [85], a little higher than the 51.5% reported in another study [88]. In addition, 53.5% of the respondents reported that they never or seldom put the unfinished leftovers into the fridge immediately after consuming [85], compared with 51.5% reported in another study [88].

20.5.3 Factors Influencing Home Food Handling Knowledge, Attitude, and Behavior

Gender, place of residence, and per capita annual income were found to be the three most important and significant factors in determining the level of knowledge of home food safety and handling, suggesting that education programs should be created and adapted for food handlers that are distinguished by these three factors [85]. In addition, educational level is also found to significantly and positively influence the level of knowledge of home food safety and handling [87]. Based on an extended model of the Theory of Planned Behavior (TPB) and a modified model of the extended TPB for the Chinese cultural context, attitude, habit, past behavior, subjective norm, face consciousness, conformity consciousness, perceived behavior control, and perceived ease are found to be significant predictors of hygienic food handling intention. Furthermore, intention was found to be particularly dependent on perceived behavior control and perceived ease, explaining the phenomenon that consumers have positive attitudes, but are less likely to generate intentions [91].

Quan and Zeng named consumer food handling behaviors, like cleaning and boiling, which occurred after food purchase and before food consumption, as “self-protective” behavior [45]. Attitude and knowledge were considered to have played a positive role in influencing consumer safe food handling behavior or “self-protective” behavior [45, 86, 88]. Consumers with more safe food handling knowledge and those that identified food handling as a very important link to avoiding food-borne disease were more inclined to handle food in the right way [45, 88]. Educational level, personal monthly income, and gender were found to positively relate with domestic meat storage, handling, and cooking practices [86]. A survey among consumers in Nanjing (southeast China) indicated that educational level and age were significantly related to food storing and handling behavior at home [87], while another survey among consumers in Guangzhou (south China) revealed that income and gender significantly affected home food handling practice [88]. Interestingly, Quan and Zeng concluded that compared with choosing safe food with safe labels, “self-protective” behaviors like cleaning and boiling were time-intensive behaviors, thus wage income had a negative influence on “self-protective” behavior. A higher wage rate will result in a lower level of self-protection due to the relatively higher opportunity cost [45]. In addition, they also pointed out that consumers of different ages choose different ways to meet their demand for food safety. Younger people are inclined to purchase more vegetables with quality labels or food safety labels while the older people are inclined to take more self-protective measures [45].

20.5.4 “High-Risk” Groups with the Poorest Home Food Handling Knowledge and Behavior

“High-risk” groups are those that are more likely to suffer food poisoning due to their poor knowledge of food safety and handling. Designing an educational program targeted at improving food handling knowledge should be based on understanding the actual level of food handlers. Identifying the demographic characteristics of groups with the lowest knowledge level is the baseline from which to build an educational program. Based on a national survey of food handlers in mainland China, Gong specifically suggested two key “high-risk” groups with the poorest knowledge of home food safety that warrant further attention: (a) males with a per capita annual income of less than 30 000 CNY; (b) females living in rural areas and with a per capita annual income of less than 30 000 CNY [86].

After analyzing domestic meat handling practices, Gong pointed out that certain consumer groups, who were found to have shown improper practices when handling meat deserve special concern: (a) the less educated, (b) rural residents, (c) those on lower incomes, and (d) males. Furthermore, the “overlaps” between and among these groups need much more attention [89]. Similarly, based on survey data collected from 18 provinces, Bai suggested that the consumer groups that demonstrate the poorest home food safety behaviors and warrant further attention are consumers educated to junior school level or below, living in urban areas, and with per capita annual incomes of less than 50 000 CNY [90]. Ye concluded that older food handlers demonstrated poorer home food handling practices and deserve special concern and targeted education [88]. However, Chen reported a different conclusion that, compared with the other groups, the respondent group in their survey, aged was between 55 and 64, demonstrated the best home food handling behavior [87].

20.6 Discussion and Future Research

To date, few researchers and Chinese consumers pay an adequate amount of attention to the problem of food-borne illness. An improvement in consumer self-protection practices toward food safety is likely to reduce the risk and incidence of food-borne disease, but there are very few studies that involve consumer self-protection practices regarding food safety, let alone how to improve consumer self-protection practices. Since food management authorities cannot intervene with every consumer, educational initiatives are required to improve consumer self-protection practices and therefore reduce the incidence of food-borne illness. Hence, future work to evaluate consumer self-protection knowledge and behavior toward food safety and to identify the demographic characteristics of the groups with the poorest knowledge or behavior is an urgent need. Studies in these fields could greatly help to inform more targeted education and to protect consumers and their families from food-borne illness and therefore reduce the incidence of illness within the food safety continuum from "farm to fork." Also, the design, provision, and evaluation of generic, managed, coordinated, general, and targeted education systems or models focused on the improvement of Chinese consumers' self-protection knowledge and behavior toward food safety remains a burning research issue in the future.

Many studies reported that Chinese consumers have a high concern about and lack of confidence in food safety, but few studies explored the negative influence of media dissemination of misleading and sensational news. In the overall view, risk communication is still in the early stages and risk communication of food safety issues is still in its infancy in China. Effective and accurate communication about food safety is very important to improve consumers' real understanding of the food safety situation in today's China. This involves a variety of experts, including government, non-profit educational organizations, scientists, and journalists. Therefore, more studies are necessary to focus on the field of "food safety, risk communication, and the Chinese consumer" in the future.

How to encourage Chinese governments to work towards a consistent and transparent approach when communicating food safety risk information? What aggressive role has media played in Chinese consumers' high concern about food safety and, in some cases, even food scares, so that many consumers question whether all food is in one way or another harmful? How to improve Chinese consumer understanding of the food safety situation in modern-day China? There is no doubt that all of these issues are very important and need further discussion in the future.

Many researchers in the domain of consumer food safety behavior and food hygiene have mentioned problems associated with self-reporting [92, 93]. Data in most of the reviewed studies are self-reported and may be subject to potential bias, such as social desirability bias. As this is a popular phenomenon in Chinese society, it would be valuable to combine an observational method or an experimental economic method with a self-reported questionnaire-based method in future research conducted in the field of consumer knowledge, attitude, and behavior toward food safety. Up to now, literature searches have revealed that there have been no studies among Chinese consumers that examined actual safe food handling behaviors at home, either by direct observation or video-recording of home behaviors.

Many studies have discovered a difference between consumer food safety knowledge, attitude, behavioral intention, and their actual behavior, the so-called knowledge–behavior, attitude–behavior, attitude–intention or intention–behavior gaps [94, 95]. However, literature searches reveal that no studies have been found to explore the gaps between Chinese consumer food safety knowledge, attitude, intention, and behavior. Many studies have discussed them, as well as consumer food safety knowledge, attitude, behavioral intention, or real behavior, but have failed to develop a unified theoretical framework to discuss knowledge, attitude, intention, and behavior together, and to explain consumer food safety knowledge–behavior or attitude–behavior correlations or gaps.

Some review studies have discussed consumer knowledge, attitude, and behavior toward the safety of food, traceable food, or homemade food, but few studies have explored consumer knowledge, attitude, and behavior toward the safety of an important food category –traditional Chinese food. Traditional Chinese food has specific features that distinguishes it clearly from other similar products in terms of the use of "traditional ingredients," "traditional composition," or "traditional type of production and/or processing method." There are many unique traditional Chinese foods, such as Yuebing (Moon cake), Huajuan (twist), Yuanxiao (glutinous rice ball), Jiaozi (dumpling), Pidan (100-year egg), Mantou (Chinese steamed buns), and Zongzi (glutinous rice pudding). There is no doubt that studies on food-borne outbreaks related to traditional food and consumer knowledge, attitude, and behavior toward the safety of traditional food is very important for promoting healthy and sustainable development of Chinese traditional food, deserving of special attention and requiring further studies.

Many models, such as the economic model, the cognitive model, and the psychological model can be used to analyze and explain consumer knowledge, attitude, and behavior toward food safety. However, only a few of the reviewed studies employed economic models like the theory of utility maximizing behavior [45, 48] and very few studies employed a psychological model like the theory of planned behavior [91] to explain consumer food safety behavior. While in many studies with no theories and analytical models that are relevant to the research problem, they are investigating what could be found. The authors did not develop an effective theoretical framework and, therefore, the establishment of their survey questions appears very arbitrary and the conclusions drawn by different studies differ greatly. Therefore, future research in the field of consumer food safety behavior must be "guided by theory" and a theoretical or conceptual framework must be developed to guide the design of survey questions, selection of methods of measuring variables, and analysis of results.

Many studies come to different conclusions, which may be due to variations in study design, survey sample, and sample size (age, sex, location, and socio-economic status), survey scales, and statistical analysis methods. Few studies use consistent scales, thus hampering comparability between studies. Furthermore, many studies have not included instruments that have proven validity or reliability. When a scale of unknown validity or reliability is used, it isn't possible to determine whether it actually measures what it claims to measure [96]. Therefore, in order to enhance measure reliability, to facilitate comparison between studies, and to determine changing trends over time, it is necessary to design and develop a set of standard food safety knowledge, attitude, and behavior scales. Furthermore, facilitating comparison between surveys has the potential to enhance the understanding of changes in consumer food safety knowledge, attitude, and behavior [97].

20.7 Conclusions

Chinese consumers have a high concern about and lack of confidence in food safety. However, the concern and perception of many consumers are not based on correct information and therefore they mistakenly assume that the food safety situation in China is getting worse. They have a high awareness of safe food, but their knowledge about the connotations of safe food like organic food and traceable food is very limited. They generally have a positive attitude to safe food, but many of them do not purchase it. Distrust of safe food and the belief that all food is almost the same in quality and safety may explain why the high ranking of safe food is not matched by regular purchases. Individual motivations, such as safe food is much safer and beneficial to health, instead of altruistic motivations, such as safe food is more environmentally friendly, are the major motivations for Chinese consumers to purchase safe food. They are willing to pay a premium for food with enhanced safety, but it should be pointed out that almost all the studies that come to that conclusion are based on self-reported data. Compared to food purchase behavior, attention has barely been paid to home food safety, consumer food handling, and preparation at home. Based on limited research, Chinese consumers demonstrate a very low level of knowledge about home food safety and handling, which may be determined by gender, age, income, and educational level. Chinese consumers' meat handling practices involve serious food safety risks. Psychological factors like attitude, perceived ease, and habit are found to be significant predictors of consumer safe food handling intention. Males with lower incomes and living in rural areas are found to be at high risk of food poisoning, due to poorer knowledge and improper practices in home food safety and handling, and therefore deserve more attention.

In order to enhance measure reliability, to facilitate comparison between studies, and to determine changing trends over time, it is necessary to design and develop a set of standard food safety knowledge, attitude, and behavior scales for future research. Also, future research should focus on using more subjective methods, such as experimental economics and observational methods, to elicit consumer knowledge, attitude, and behavior toward food safety. Furthermore, consumer-specific attitude and behavior toward the safety of Chinese traditional food deserves special attention and requires further study. In addition, exploring the gap between food safety knowledge and behavior, attitude and behavior, attitude and intention, and intention and behavior in the Chinese cultural context is another field for future research. Also, more studies are necessary that focus on the field of risk communication to interpret the Chinese consumers' perception of risk, bridge the divide between expert analysis of the risk equation on one side and public reaction and action on the other, and restore and increase consumer food safety confidence. Finally, future work to evaluate consumer self-protection knowledge and behavior toward food safety and identify the demographic characteristics of the groups with the poorest knowledge or behavior is an urgent need. Studies in these fields could greatly help to inform these groups through targeted education and to protect consumers and their families from getting foodborne illnesses.

Acknowledgements

The authors wish to thank the National Natural Science Foundation of China (NSFC) for funding our project titled "Self-protection practice toward food safety: Theory development, empirical test and interventional trial (No. 71573103)". The authors are also grateful to Desautels Faculty of Management, McGill University, Canada, where the authors completed the writing of this chapter and spent 12 months as visiting scholars, for providing supportive working environments. Special thanks are given to Prof. Shanling Li in Desautels Faculty of Management, McGill University for her personal support and for the many valuable discussions. Last, the authors also give their gratitude to the financial support of the China Scholarship Council (CSC) for supporting the visit to McGill University.

References

1 Bai, L., Ma, C., Gong, S., and Yang, Y. (2007). Food safety assurance systems in China. *Food Control*, 18, 480–484.
2 Redmond, E. C. and Griffith, C. J. (2009). The importance of hygiene in the domestic kitchen: Implications for preparation and storage of food and infant formula. *Perspectives in Public Health*, 129, 2, 69–76.
3 Nesbitt, A., Thomas, M. K., Marshall, B., Snedeker, K., Meleta, K., Watson, B., and Bienefeld, M. (2014). Baseline for consumer food safety knowledge and behavior in Canada. *Food Control*, 38, 157–173.
4 Jacob, C., Mathiasen, L., and Powell, D. (2010). Designing effective messages for microbial food safety hazards. *Food Control*, 21, 1–6.
5 Xue, J. and Zhang, W. (2013). Understanding China's food safety problem: An analysis of 2387 incident of acute foodborne illness. *Food Control*, 30, 311–317.
6 National Health and Family Planning Commission (NHFPC). (2015). Notice of the general office of the national health and family planning commission on the national food poisoning incidents in 2014. *Gazette of the National Health and Family Planning Commission of People's Republic of China*, 2, 4–5. Available at: http://www.nhfpc.gov.cn/ewebeditor/uploadfile/2015/06/20150601174928141.pdf. (accessed March 2016) [in Chinese].
7 Wang, H., Ni, C., and Xu, R. (2011). Consumer's willingness to pay on food quality and label safety: A case study of pork consumption in Nanjing city. *Journal of Nanjing Agricultural University (Social Sciences Edition)*, 11, 1, 21–29 [in Chinese].
8 Huang, K. S. and Gale, F. (2009). Food demand in China: Income, quality, and nutrient effects. *China Agricultural Economic Review*, 1, 4, 395–409.
9 Ortega, D. L., Wang, H. H., Olynk, N. J., Wu, L., and Bai, J. (2012). Chinese consumers' demand for food safety attributes: A push for government and industry regulations. *American Journal of Agricultural Economics*, 94, 2, 489–495.
10 Zhang, X. (2005). Chinese consumers' concerns about food safety. *Journal of International Food and Agribusiness Marketing*, 17, 1, 57–69.
11 E, F. (2012). Food Safety Ranks Top 1. *Well-off*, 12, 64–68 [in Chinese].
12 Ren, Y. and An, Y. (2009). Chinese consumers' food safety confidence and its influence factors: A survey in Peking Nongmao markets. *Consumer Economics*, 25, 2, 45–48 [in Chinese].

13 Zhou, Y, Huo, L, and Peng, X. (2004). Food safety: consumers' attitude, behavior intention and the influence of information: a survey on supermarket consumer in Nanjing City. *Chinese Rural Economy*, 11, 53–59 [in Chinese].

14 Xu, L., and Wu, L. (2010). Food safety and consumer willingness to pay for certified traceable food in China. *Journal of the Science of Food and Agriculture*, 90, 1368–1373.

15 Han, Y., Cao, B., Chen, J., and Mao, Z. (2014). Variance analysis on Chinese consumers' demand for information of food quality and safety: Empirical test of data from 1573 Chinese consumers. *China Soft Science*, 2, 32–45 [in Chinese].

16 Yin, S., Chen, M., Xu, Y., and Li, Z. (2013). Validation of the policy of organic food certification in China: From a view of consumer trust. *Journal of Public Management*, 10, 3, 110–119 [in Chinese].

17 Cicia, G., Caracciolo, F., Cembalo, L., Del Giudice T., Grunert, K.G., Krystallis, A., Lombardi, P., and Zhou, Y. (2016). Food safety concerns in urban China: Consumer preferences for pig process attributes. *Food Control*, 60, 166–173.

18 Teng, Y. (2011). Chinese consumers' awareness and behavior toward food safety. *Consumer Economics*, 27, 2, 74–77 [in Chinese].

19 Wu, L., Liu, X., Zhu, D., Wang, H., Wang, S., and Xu, L. (2015). Simulation of market demand for traceable pork with different levels of safety information: A case study in Chinese consumers. *Canadian Journal of Agricultural Economics*, 63, 513–537.

20 Veeck, G., Veeck, A., and Zhao, S. (2015). Perceptions of food safety by urban consumers in Nanjing, China, *The Professional Geographer*, 67, 3, 490–501.

21 Cheng, L., Yin, C., and Chien, H. (2014). Demand for milk quantity and safety in urban China: Evidence from Beijing and Harbin. *Australian Journal of Agricultural and Resource Economics*, 59, 275–287.

22 Zhang, C., Bai, J., Lohmar, B., and Huang, J. (2010). How do consumers determine the safety of milk in Beijing, China? *China Economic Review*, 21, 45–54.

23 Lu, F., He, P., and Min, R. (2010). Factors affecting Chinese consumers' confidence in food safety. *Journal of Northwest A andF University (Social Science Edition)*, 10, 1, 72–77 [in Chinese].

24 Qiao, G., Guo, T., and Klein, K. (2010). Melamine in Chinese milk products and consumer confidence. *Appetite*, 55, 190–195.

25 Qiao, G., Guo, T., and Klein, K. (2012). Melamine and other food safety and health scares in China: Comparing households with and without young children. *Food Control*, 26, 378–386.

26 Dong, X., and Li, Z. (2016). Food safety issues in China: A case study of the dairy sector. *Journal of the Science of Food and Agriculture*, 96, 346–352.

27 Wang, Z., Li, T., and Huang, S. (2013). Chinese consumer food safety perception and the restore of confidence: Take tainted milk powder as an example. *Consumer Economics*, 29, 4, 42–47 [in Chinese].

28 Zhou, Y., and Zhuo, J. (2010). Risk perceptions of Chinese consumers: A survey on melamine incident among Nanjing consumers. *Agricultural Techno-Economy*, 2, 89–99 [in Chinese].

29 Gong, S., Bai, L., and Chen, J. (2012). Chinese consumers' confidence in food safety: An analysis based on the structural equation modeling. *Consumer Economics*, 28, 2, 53–57 [in Chinese].

30 Cui, B., Yin, J. (2012). An empirical study on the formation mechanism of consumer's trust of food safety: Based on 862 survey data from Jiangsu province. *Economic Survey*, 2, 115–119 [in Chinese].

31 Qiu, H., Huang, J., and Yang, J. (2007). Consumers' trust in government and its impact on their acceptance toward genetically modified food. *Economic Research Journal*, 6, 65–75 [in Chinese].

32 Liu, Y., Zhou, X. (2009). Formation mechanism of consumers' trust in food safety. *Modern Management Science*, 7, 55–57 [in Chinese].

33 Chen, W. (2013). The effects of different types of trust on consumer perceptions of food safety: An empirical study of consumers in Beijing Municipality, China. *China Agricultural Economic Review*, 5, 1, 43–65.

34 Cui, B., and Yin, J. (2012). An empirical study on the formation mechanism of consumer's trust of food safety: Based on 862 survey data from Jiangsu province. *Economic Survey*, 2, 115–122 [in Chinese].

35 Huang, J., and Peng, B. (2015). Consumers' perceptions on GM food safety in urban China. *Journal of Integrative Agriculture*, 14, 11, 2391–2400.

36 Peng, Y., Li, J., Xia, H., Qi, S., and Li, J. (2015). The effects of food safety issues released by we media on consumers' awareness and purchasing behavior: A case study in China. *Food Policy*, 51, 44–52.

37 Chen, J. (2011). The success or failure of health news may be due completely to the media. *Health Management*, 2, 1, 44–45 [in Chinese].

38 Wu, L., Zhong, Y., and Shan, L. (2013). Influence factors of consumer risk perceptions on food additives. *Chinese Rural Economy*, 5, 45–57 [in Chinese].

39 Sun, B. (2011). Food additives and food safety. *Scientific Chinese*, 22, 33–37 [in Chinese].

40 Chen, S., Wu H., Lu, X., Zhong, K., Xie, X., Li, X., Lu, X., and Guo, L. (2015). The Public's Risk Perception on Food Additives and the Influence Factors. *Journal of Chinese Institute of Food Science and Technology*, 15, 3, 151–157 [in Chinese].

41 Chen, J., and Han, F. (2015, April 28). Counterfeit food dose not equal to unsafe food. *China Food Safety News*, pp. A02 [in Chinese].

42 Chen, J. (2016, January 8). What is the most serious food safety problem of the today's China? *China Food News*, pp. 003 [in Chinese].

43 Chen, J. (2014, April 20) How serious is the foodborne illness in China? *Beijing Science and Technology News*, pp. 052 [in Chinese].

44 World Health Organization. WHO estimates of the global burden of foodborne diseases: foodborne disease burden epidemiology reference group 2007 – 2015. http://apps.who.int/iris/bitstream/10665/199350/1/9789241565165_eng.pdf?ua=1 (accessed May 2016).

45 Quan, S. and Zeng, Y. (2014). Food Safety Consumers' label – choosing and self – protection behaviors. *China Population, Resources and Environment*, 4, 77–85.

46 Zhou, Y., and Peng, X. (2006). Consumer willingness to pay for food safety in Jiangsu province of China: A case study of reduced pesticide residues. *China Economic Quarterly*, 5, 4, 1319–1339 [in Chinese].

47 Yin, S., Xu, Y., and Chen, Y. (2015). How do food quality information label affect consumers preferences: Based on the choice experiment of 843 samples in Shandong province. *China Rural Survey*, 121, 1, 39–50 [in Chinese].

48 Zhang, Z., Qiao, J., and Huang, S. (2013). Heterogeneity in Consumer Preference for food safety contributes in China. *Agricultural Techno-Economy*, 5, 95–104 [in Chinese].

49 Wang, Z., Mao, Y., and Gale, F. (2008). Chinese consumer demand for food safety attributes in milk products. *Food Policy*, 33, 27–36.

50 Zhang, L., and Han, L. (2009). An analysis on consumer perception of safe food and purchase behavior: A survey on fresh food in Shanghai. *Chinese Agricultural Science Bulletin*, 25, 4, 50–54 [in Chinese].

51 Ortega, D., Wang, H., Wu, L., and Hong, S. (2015). Retail channel and consumer demand for food quality in China. *China Economic Review*, 36, 359–366.

52 Zhong, F., and Yi, X. (2010). Analysis on difference between consumers' concerns and actual purchasing behavior regarding food safety: Case study of vegetable consumption in Nanjing. *Journal of Nanjing Agricultural University (Social Sciences Edition)*, 10, 2, 19–28 [in Chinese].

53 Cicia, G., Caracciolo, F., Cembalo, L., Del Giudice T., Grunert, K.G., Krystallis, A., Lombardi, P., and Zhou, Y. (2016). Food safety concerns in urban China: Consumer preferences for pig process attributes. *Food Control*, 60, 166–173.

54 Ortega, D., Wang, H., and Wu, L. (2009). Food safety and demand: Consumer preferences for imported pork in urban China. *Journal of Food Distribution Research*, 40, 3, 52–64.

55 Wu, L., Yin, S., Xu, Y., and Zhu, D. (2014). Effectiveness of China's organic food certification policy: Consumer preferences for infant milk formula with different organic certification labels. *Canadian Journal of Agricultural Economics*, 62, 4, 545–568.

56 Han, Y. and Qiao, J. (2009). Influence factors of consumers' attitude and willingness to pay for traceable foods in China: A test and analysis on the survey from Beijing. *Technology Economics*, 28, 4, 37–44 [in Chinese].

57 Wu, L., Xu, L., Zhu, D., and Wang X. (2012). Factors affecting consumer willingness to pay for certified traceable food in Jiangsu province of China. *Canadian Journal of Agricultural Economics*, 60, 317–333.

58 Zheng, S., Xu, P., Wang, Z., and Song, S. (2012). Willingness to pay for traceable pork: Evidence from Beijing, China. *China Agricultural Economic Review*, 4, 2, 200–215.

59 Bai, J., Zhang, C., and Jiang, J. (2013). The role of certificate issuer on consumers' willingness-to-pay for milk traceability in China. *Agricultural Economics*, 44, 537–554.

60 Liu, Z., and Qiao, J. (2011). Consumers' cognition of certificated food and its influential factors: A survey in Dalian City. *Consumer Economics*, 27, 4, 11–14 [in Chinese].

61 Liu, R., PieniaK, Z., and Verbeke, W. (2013). Consumers' attitudes and behavior towards safe food in China: A review. *Food Control*, 33, 93–104.

62 Ma, J., and Qin, F. (2009). Consumers' cognition of safe agricultural products and its determinants: An empirical study on consumer behavior to organic food of urban consumers in Beijing. *China Rural Economy*, 5, 26–34 [in Chinese].

63 International Trade Center. (2011). *Organic food products in China: Market review (Technical paper).* Geneva: ITC. Doc. No. SC-11-196.E 2011.

64 Zhang, H. Y. (2010). Consumer behavior to green agricultural products and its influential factors in Guangzhou city. *Journal of Northwest A and F University (Social Science Edition)*, 10, 4, 53–56 [in Chinese].

65 Liu, Z., and Qiao, J. (2015). Consumers' loyalty of quality certification label and its impact on food purchasing behavior in preference restrain: Taking pork product as example. *Food and Nutrition in China*, 21, 10, 49–55 [in Chinese].

66 Liu, J. D., Wang, K., and Han, J. Q. (2009). Consumers' cognition and purchasing behavior of organic pork: A survey in Shanghai and Nanjing. *Modern Economic Research*, 4, 50–53 [in Chinese].

67 Zheng, Y. (2009). A review of consumers' purchases behavior toward organic food. *Jiangsu Commercial Forum*, 3, 42–44 [in Chinese].

68 Wang, X., Xiao, X., Zhang, A., and You, W. (2009). Study on consumers' attitude towards organic food in Nanjing, China. *Journal of Anhui Agricultural Science*, 37, 14, 6795–6796 [in Chinese].

69 Dai, Y., Zhu, B., and Ying, R. (2006). Chinese consumer purchase intention of organic food: A survey of organic vegetables among consumers in Nanjing city. *Journal of Nanjing Agricultural University (Social Sciences Edition)*, 6, 1, 47–52 [in Chinese].

70 Yang, Y. (2012).An analysis on main influencing factors about organic food purchase: Based on the consumer survey in city. *On Economic Problems*, 7, 65–69 [in Chinese].

71 Xie, Y., and Gao, Y. (2013). Analysis on consumers' cognition and purchasing behavior toward organic food. *Journal of Jiangnan University (Humanities and Social sciences)*, 12, 1, 124–228 [in Chinese].

72 Wang, N., and He, J. (2016). Influence factors of decision on organic food purchase. *Consumer Economics*, 32, 1, 73–78 [in Chinese].

73 Yang, N. (2015). Empirical research on influence factors of consumers purchasing behavior about organic foods. *Journal of Central University of Finance and Economics*, 5, 89–95 [in Chinese].

74 Yin, S., Wu, L., Du, L., and Chen, M. (2010). Consumers' purchase intention of organic food in China. *Journal of the Science of Food and Agriculture*, 90, 1361–1367.

75 Zhou, Y., Ma, R., and Wang, E. (2014). Analysis on differences between consumer risk perception of food safety and recovery purchasing behavior: A case of dairy consumption in Nanjing. *Journal of Nanjing Agricultural University (Social Sciences Edition)*, 14, 1, 111–117 [in Chinese].

76 Quan, S., Zeng, Y., Liu, Y., and Y, X. (2011). Resumption of food after an accident: Taking melamine scandal as an example. *Agricultural Techno-Economy*, 7, 4–15 [in Chinese].

77 Liu, Y., and Zeng, Y. (2014). Risk communication and trust in government and consumers' recovery behavior: A case study of the melamine incident. *Social Science of Beijing*, 3, 52–63 [in Chinese].

78 Li, Y., Liu, M., and Ping, Y. (2015). Consumers' purchase intention fluctuation after food safety incident: Based on terror management dual-process perspective. *Management Review*, 27, 6,186–196 [in Chinese].

79 Chen, W., Xu, Y., Liu, Z., and Lv, Y. (2014). Cause Analysis of Food Poisoning in Sichuan, 2004-2012. *Journal of Preventive Medicine Information*, 30, 8, 613–617 [in Chinese].

80 Liu, D., Tang, G., and Liu, Y. (2010). Analysis of chemical food poisoning condition in China from 2004 to 2008. *Practical Journal of Medicine and Pharmacy*, 27, 3, 254–257 [in Chinese].

81 Li, T. Analysis of the food poisoning in China from 2002 to 2011. (2012). *Journal of Shanxi Medical University*, 43, 6, 428–431 [in Chinese].

82 Sun, L. (2006). Analysis on epidemiological characteristics of 184 food poisoning incidents in rural families. *Chinese Rural Health Service Administration*, 26, 5, 60–62 [in Chinese].

83 Zhao, Y., Wang, Z., Liu, B., Zeng, B., Chen, H. and Jiang, T. (2012). Epidemiology of food poisoning in Zhejiang province, 2006-2011. *Disease surveillance*, 27, 4, 307–310 [in Chinese].

84 Wu, Y., Wen, J., Ma, Y., Ma, X., and Chen, Y. (2014). Epidemiology of foodborne disease outbreaks caused by virbrio parahaemolyticul, China, 2003–2008. *Food control*, 46, 197–202.

85 Teng, Y. (2011). Chinese consumers' awareness and behaviors toward food safety. *Consumer Economics*, 27, 2, 74–77 [in Chinese].

86 Gong, S., Wang, X., Yang, Y., and Bai, L. (2016). Knowledge of food safety and handling in households: A survey of food handlers in Mainland China. *Food Control*, 64, 45–53.

87 Chen, G., Sun, G., Wang, S., Sheng, J., Xu, H., Li, H., Liu, S., and Guo Y. (2006). KAP survey on food safety among customers in Nanjing city. *Chinese Journal of Public Health*, 22, 5, 603–604 [in Chinese].

88 Ye, W., Zeng, M., and Lin, J. (2012). Safe preparation of food and its influencing factors among families in Guangzhou city. *Chinese Journal of Public Health*, 28, 3, 312–314 [in Chinese].

89 Gong, S., Yang, Y., Shen, H., Wang, X., Guo, H., and Bai, L. (2011). Meat handling practices in households of Mainland China. *Food Control*, 22, 749–755.

90 Bai, L., Tang, J., Wang, L., and Gong, S. (2014). Consumer food safety behavior and an examination of "high-risk" consumers in China. *Consumer Economics*, 30, 1, 43–46 [in Chinese].

91 Bai, L., Tang, J., Yang, Y., and Gong, S. (2014). Hygienic food handling intention. An application of the Theory of Planned Behavior in the Chinese cultural context. *Food Control*, 42, 172–180.

92 Millman, C., Rigby, D., Edward-Jones, G., Lighton, L., and Jones, D. (2014). Perceptions, behaviours and kitchen hygiene of people who have and have not suffered campylobacteriosis: a case control study. *Food Control*, 41, 82–90.

93 Mullan, B., and Wong, C. (2010). Using the Theory of Planned Behavior to design a food hygiene intervention. *Food Control*, 21, 1524–1529.

94 Padel, S., and Foster, C., (2005) Exploring the gap between attitudes and behaviour: Understanding why consumers buy or do not buy organic food. *British Food Journal*, 107, 8, 606–625.

95 Vermeir, I., and Verbeke, W. (2006). Sustainable food consumption: Exploring the consumer "attitude-behavioral intention" gap. *Journal of Agricultural and Environmental Ethics*, 19, 169–194.

96 Parmenter K, and Wardle J. (2000). Evaluation and design of nutrition knowledge measures. *Journal of Nutrition Education*, 32, 269–277.

97 Nesbitt, A., Thomas, M. K., Marshall, B., Snedeker, K., Meleta, K., Watson, B., and Bienefeld, M. (2014). Baseline for consumer food safety knowledge and behavior in Canada. *Food Control*, 38, 157–173.

Part 5

Risk Management

21

Food Safety Laws and Regulations

Yunbo Luo and Guangfeng Wu

College of Food Science and Nutritional Engineering, China Agricultural University, China

21.1 Overview: The Importance of Laws and Regulations for Food Safety

The rule of law is closely related to national food safety governance. In a modern society, the rule of law is essential to a nation's governance, which needs to be reviewed constantly in order to modernize. China has successively promulgated the Food Hygiene Law, the Product Quality Law, the Food Safety Law and other relevant laws and regulations since the 1990s. These laws have helped to guard the safety, quality and nutritional values of the food products produced in China. The administrative bodies under the guidance of the State Council and the relevant ministries have also issued a series of regulations and implementation rules. To a certain extent, they have played an active role in China's food safety supervision in accordance with China's cultural conditions. Improving and perfecting the laws, regulations, legal systems, legal procedures and law enforcement mechanisms of the nation's food safety controls are the cornerstones of a complete and scientific governance system for China's food safety system.

21.1.1 They are Necessary to Protect Citizens' Right to Health

In modern societies with rules of law,the basic rights of citizens are generally respected and protected. The right to good health and life is at the core of this legal protection. The essence of laws and regulations related to food safety is to protect the lives and health of the citizens. Normally, the inherent constraints in the moral autonomy of food producers and traders would not be able to exert effects in the face of temptations from economic gains. Thus, heteronomous constraints become critical. Therefore, it is necessary to introduce heteronomous mechanisms to effectively regulate the behavior of the producers and the traders. On the other hand, in a modern society ruled by law, the use of legal means to regulate the behavior of producers and traders should provide a relatively fair and efficient regulatory path for the business to make profits as well [1].

Food Safety in China: Science, Technology, Management and Regulation, First Edition.
Edited by Joseph J. Jen and Junshi Chen.

21.1.2 They are Necessary for the Healthy Development and Operation of the Market Economy

Laws are produced and developed to adapt to the needs of the market economy, and thus, they act as anchors for this economy. The market economy requires good faith as a pre-condition, and the transaction parties will achieve economic success on the basis of mutual benefits and win-win choices. The bartering behavior of some food producers and traders not only disturbs the normal market order, but it also harms the interests of consumers and thereby affects social and economic stability, as evidenced by the Sanlu milk powder incident that occurred in 2008 and the Henan Shuanghui clenbuterol-tainted meat product incident in 2011. However, China is known as the “world’s factory” and it engages in a huge volume of international trade. Agriculture is the foundation of the national economy. China is one of the agricultural giants of the world and agricultural products account for a large share of China’s exports. Therefore, once there is a food safety problem, other countries will levy more stringent restrictions on China’s food exports. They sometimes use the problem as an excuse to create trade barriers. These restrictions lead to a lack of timely transactions of wholesome and high-quality food products, which is bound to cause heavy losses for the nation’s food industry.

21.1.3 They are Needed for Social Order and Political Stability

Food safety issues often have a very important association with the optimization of social resources, social equity, and justice, as well as the security and the stability for society. Harmful food products not only waste material resources, but also damage human health and safety. If the legitimate rights of consumers cannot be effectively maintained, social order will be endangered. In a modern society, one of the most important functions of the government is to remedy the shortcomings of the market economy and to provide public goods and services such as education, health and hygiene. Thus, laws and regulations related to food safety play an important role in the maintenance of social order and political stability.

21.1.4 The Composition of Chinese Law and its Regulatory System

The Chinese legal system is based on the Constitution of the People’s Republic of China and it is composed of the written laws, regulations and rules set up by local legislation and the special administration region (SAR), and laws established from international treaties that are signed by the Chinese government. Judicial precedents have no binding power, but they provide judicial references and guidance.

The Constitution of the People’s Republic of China authorizes the Chinese National People’s Congress (NPC) and the NPC Standing Committee to exercise legislative power. The NPC has the authority to amend the constitution and to enact and amend basic laws related to governmental agencies and civil and criminal matters. In addition to the laws that the NPC enacts and amends, the NPC Standing Committees are authorized to enact and amend all laws. The State Council is the highest administrative authority in the nation and it is authorized to enact the administrative rules and regulations. Various ministries and commissions under the State Council have the authority to issue specific orders, directives and regulations within their respective jurisdictions or departments. All administrative rules, regulations, directives and orders that are promulgated by the State Council and its ministries and commissions must be consistent with the Chinese Constitution and the laws authorized by the NPC. In case of conflict, the NPC Standing Committee has the right to annul any administrative rules, regulations, directives and orders.

At local government level, the provincial and municipal People's assemblies and their respective standing committees may enact specific local rules and regulations applicable to their own region only. These local laws and regulations must also be consistent with the Chinese Constitution, the national laws and administrative rules, and the regulations promulgated by the State Council.

The State Council and provincial and municipal governments may also enact or issue rules, regulations or directives in new legal fields for experimental purposes. After trial measures gain adequate experience, the State Council may submit legislative proposals to the NPC or the NPC Standing Committees to issue national legislations.

The Constitution of the People's Republic of China authorizes the NPC Standing Committee to interpret the laws, according to "The Resolution of the NPC Standing Committee on Strengthening Legal Interpretation Work," which was passed on June 10, 1981. The Supreme People's Court, in addition to the right to interpret the law during the judicial process, also has the right to interpret specific cases. The State Council and its ministries and commissions also have the authority to interpret the rules and regulations that they proclaim. At the local level, legal interpretation authority is granted to the legislative and administrative bodies that issued the laws.

21.2 History

Over the past decade, China has declared a series of laws and regulations related to food safety as the nation laid a solid legal foundation for enhancing food safety. China has established a fairly complete food safety law and regulation system that includes basic laws such as the Food Safety Law, the Product Quality Law, the Agricultural Product Quality and Safety Law, and the Agricultural Law. The basic core regulations involve relevant technical standards for food safety as an important element. The food safety regulations for each province and local government serve as important complements.

Since June 1, 2009, China has begun to implement the People's Republic of China first Food Safety Law. At the same time, the People's Republic of China Food Hygiene Law that was initiated on October 30, 1995 was abolished. The Food Safety Law has 104 items distributed over 10 chapters [2], which include general provisions, food safety risk detection and evaluation, national food safety standards, food production and management (production processing, food service and food circulation), food quality and safety inspection, food import and export management, food safety incident handling, supervision and management systems, legal liability and supplementary provisions, and basic concepts of food safety, among others. The Food Safety Law is the base law that covers all areas of food safety. On the one hand, it presents the overall framework and points towards the formulation of food safety laws. On the other hand, it adds a food safety risk detection and evaluation system, a recall system, national food safety standardization management and publishing, and other details to ensure that food quality and safety objectives are implemented in a scientific and rational manner.

In comparison with the old Food Hygiene Law, the Food Safety Law has made great breakthroughs and improvements in the object and body of legal protection in the regulatory model and the scientific development of standards. For the first time, it introduces the food safety concept for the entire food production process ("from farm to fork").

Since the issue and implementation of the Food Safety Law, the Chinese government has brought in relevant experts to develop and implement the regulations and the "Implementation of the Food Safety Law" to ensure its effectiveness [3]. The provincial governments have also actively organized experts from various fields to quickly develop supporting implementation details in the Food Safety Law.

A number of scientific and advanced legal systems have been introduced into the Food Safety Law and Regulations for its implementation, such as the food safety risk detection and evaluation system, food recall system and food safety standards from the legislative provisions. The law only provides the macro-regulatory principles. They are often expounding on the connotations of the legal system and may lack operability provisions that pertain to the food safety field [4]. For example, Article 16.2 of the Food Safety Law decrees that for foods that are deemed unsafe for consumption after food safety risk assessment study, the relevant authorities must take appropriate measures and inform consumers about the risks in detail. Within the legal system that addresses food safety risk detection and evaluation, whenever the assessment result reveals unsafe food, one department among the three agencies (the Quality Supervision Commission of the State Council, the Industry and Commerce Administration Commission, and the State Food and Drug Commission) is supposed to be responsible for informing the food producer that they must stop production and to notify consumers not to use the unsafe food. The legislative provision does not explicitly clarify which agency is to deal with this issue, which results in disputes over the issues and leads to avoiding responsibility. The departments either do not fulfill their notification obligation, or they do not fulfill the obligation to producers to stop production of the unsafe foods, thus losing administrative efficiency. For example, the Food Safety Law indicates that The Quality Supervision Commission of the State Council, the Industry and Commerce Administration Commission and the State Food and Drug Administration are in charge of the supervision and the management of food production, food distribution and food service activities. The responsibility of the State Food Safety Commission is to primarily coordinate the nation's food safety supervision and management, which is essentially the same responsibility as the comprehensive coordination of food safety function within the Hygiene Administration Department of the State Council. The only difference may be at the legal level, with one being authorized through regulations and another being authorized through laws. It is worth noting that according to the Food Safety Law and the Implementing Regulations of the Food Safety Law, some terms are so ambiguous that it is difficult for executive authorities to grasp their meaning. Thus, the laws are not operable with regard to terms such as "relevant departments," relevant sectors," and so on, which is bound to influence the efficiency of law enforcement.

In the context of China's food safety laws, "food" and "edible agricultural products" are conceptually different and not mutually inclusive, and theoretically there should not be any cross-over. According to the provisions of the Food Safety Law, "edible agricultural products" refers to "edibles derived from primary agricultural products," and the concept of "food" can be generated by using the exclusion method, such as all other foods except for edible agricultural products. In the 2009 edition of the Food Safety Law, Article 2 clearly states that the quality and safety management of edibles derived from primary agricultural projects (hereinafter referred to as edible agricultural products) must comply with the Agricultural Product Quality and Safety Law of the People's Republic of China. However, the marketing of edible agricultural products, the development of the relevant quality and safety standards, the disclosure of relevant safety information and the regulations asserted by this law on agricultural inputs should comply with the current law.

The aforementioned Agricultural Product Quality and Safety Law of the People's Republic of China is currently China's most authoritative core agricultural law. Enacted by the State Council in 2006, it holds the same legal status as the Food Safety Law. It was the first law to be specifically created for the quality and safety of agricultural products, and it consists of 56 items in eight articles [5]. These articles cover the whole regulatory process relating to agricultural products from farm to market, including legal provisions for the agricultural production base, the production of agricultural products, the quality and safety standards of agricultural products, supervision and inspection, and the packaging and labeling of the agricultural products, as well as the legal liabilities. In addition, the competent administrative authorities on the agriculture side have a subjective status in the united regulation of the quality and safety of agricultural products. They have duties and powers for each relevant quality and safety-supervising entity that establishes the basis for the regulatory system and law enforcement. This phenomenon of two parallel laws is rare around the world, also making China's system of food safety laws unique.

To date, laws and regulations related to the quality and safety of agricultural products that have been proclaimed in China also include a Standardization Law, an Environmental Protection Law, a Water Pollution Prevention Law, an Anti-Unfair Competition Law, a Consumer Protection Law and other comprehensive laws and administrative regulations. Such laws and regulations include the Agriculture Law, the Safety Regulations On Genetically Modified Organisms Law, the Seed Law, the Entry and Exit Animal and Plant Quarantine Law of the People's Republic of China, the Pesticide Management Regulations, the Animal Epidemic Prevention Law of the People's Republic of China, the Fishery Law, the Grassland Law, the Administrative Regulations On Feed and Feed Additives, the Administrative Regulations On Veterinary Medicines, and others.

The Product Quality Law is a very important law in China that was issued to strengthen the supervision and management of product quality. It clarifies the responsibility for product quality, protecting the legitimate rights and interests of consumers and maintaining social and economic order [6]. This law was passed on 22 February 1993 and was formally implemented on 1 September 1993. The first amendment of this Law was based on the "Decision on the amendment of the 'Product Quality Law of People's Republic of China'" by the 16th meeting of the 9th NPC Standing Committee on 8 July 2000. The amended Product Quality Law was formally implemented on 1 September 2000.

The Product Quality Law specifies the responsibilities and permissions given to the supervision and management authorities at the various levels, starting at the macro level and clarifies the quality responsibilities and obligations of the producers and the sellers. These laws have played a very important role in improving the quality and safety of food products in China.

In terms of linking production and marketing of agricultural products, China has not yet implemented the universally mandatory HACCP system. However, the food market access system has been adopted with a license system for food production and processing. Food-processing enterprises are required to have appropriate minimum sanitary conditions such as production equipment, detection measures, and so on. Otherwise, the license is not issued, and the food products are not allowed to enter the market. Therefore, food quality is effectively guaranteed. Since January 1, 2004, the food safety market access mechanism has been applied to five types of food industry: rice, wheat flour, soy sauce, vinegar and edible vegetable oil. Later, it was further implemented into 38 types of food products, including meat products, dairy products, convenience foods, biscuits, puffed foods, frozen food, condiments, canned food, beverages, and so on.

There are two offenses in "China's Criminal Law" that are related to food safety: (i) the manufacturing and selling foods that do not comply with hygiene standards (Article 143), and (ii) the manufacturing and selling of poisonous and harmful foods (Article 134).

On 25 February 2011, the 19th meeting of the NPC Standing Committee passed The Eighth Amendment to the People's Republic of China Criminal Law, which was implemented on 1 May 2011. The Eighth Amendment made the following two modifications to Article 143 [7]: (i) For the crime of manufacturing and selling food products that do not comply with hygiene standards, but do not result in serious consequences, the imposition of a single punishment with a fine was abolished. Prior to the implementation of the Eighth Amendment, for the crime of manufacturing and selling food products that do not comply with hygiene standards, but do not result in serious consequences, the court could only impose fines on the unit, and the responsible person(s) might not be punished. After the implementation of the Eighth Amendment, not only is the fine imposed, but those who are responsible are also punished with imprisonment or criminal detention. (ii) Prior to the implementation of this amendment, the maximum penalty to the offenders must not exceed twice the value of the product sold. The Eighth canceled this penalty limit. Incorrigible offenders who manufacture and sell food products that do not meet hygiene standards can be fined until bankrupcy.

The Eighth Amendment made four modifications to Article 134 of the Criminal Law as follows [7]: (i) The levy of a single fine was cancelled, and the court can sentence the responsible personnel to jail terms in addition to imposing a penalty on the unit and (ii) it aggravated the penalty for the given violations. According to the Criminal Law, offenders who commit the crime of manufacturing and selling toxic and harmful food can be sentenced to a fixed term of imprisonment of one to six months. After the implementation of the Eighth, offenders who commit the crime of manufacturing and selling toxic and harmful food are sentenced to at least six months of imprisonment, and (iii) the scope of harmful consequences has been expanded. According to the Criminal Law, only crimes that cause serious harm to human health are punishable with a fixed-term of imprisonment of five years as a minimum and 10 years as a maximum. The Eighth Amendment adds the phrase, "or other serious circumstances" to another phrase, "causing serious harm to human health." After the adoption of this Criminal Law amendment, offenders who commit the crime of manufacturing and selling toxic and harmful food, but do not cause serious harm to human health, can be sentenced to a fixed-term imprisonment of five years when there is a "serious circumstance" and [4] the fine ceiling amount was cancelled. Offenders who commit the crime of manufacturing and selling toxic and harmful food can have all their assets confiscated.

There is one more important element in the Eighth Amendment to the People's Republic of China Criminal Law. Article 408.1 was added to Article 408 of the Criminal Law: "Functionaries of state organizations that bear the responsibilities of food safety supervision and management who abuse their power or neglect their duties, leading to major food safety accidents or other serious consequences, are punishable with a fixed-term imprisonment of up to five years. In cases causing serious consequences, they are punishable with a fixed-term imprisonment between five years and ten years. Offenders with fraudulent practices are punishable with more aggravated penalties."

According to the scope of implementation, China's standards can be divided into three types: (i) national standards, (ii) local standards and (iii) corporate standards. In the past, there were redundancies, crossovers and contradictions among these three standards. For example, there were two simultaneous standards on pollutant limits, namely, the national and local standards. This phenomenon caused tremendous confusion among producers, which then affected the interests of consumers. The 2009 version of the Food Safety Law clearly stipulates that the existing quality of edible agricultural products and the safety standard, food hygiene standard, food quality standard and the relevant food industry standards should be sorted, integrated and unified into one mandatory national food safety standard. By the end of 2013, China had launched a clean-up of nearly 5000 mandatory enforcement items relating to the quality and safety standards of edible agricultural products, food hygiene standards, food quality standards and industry standards. It has announced more than 300 national food safety standards, specialty standards for dairy safety, mycotoxins, pesticide and veterinary drug residuals, food additive use, labeling and nutrition fact labeling for prepackaged food, and contaminant limits in food. These standards cover thousands of specifications related to the health hazards in the various foods. The clean-up and integration of the basic standards in China's food safety system have been essentially accomplished.

21.3 Current Situation (January 2014 to June 2015)

On 14 March 2013, the first meeting of the 12th NPC approved the "Resolution on the institutional reform and functional transformation scheme of the State Council (draft)," which proposed that the duties of the food safety office, the food and drug administration and the food safety administration oversee the production link with the State Bureau of Technical Supervision. The duties of the food safety administration oversee the circulation link of the SAIC being consolidated to form the General Administration of Quality Supervision, Inspection and Quarantine (AQSIQ) of the People's Republic of China. The primary responsibility of this administration is to implement unified supervision and management of food safety and to ensure the safety and effectiveness of drugs during the production, circulation and consumption links. To this end, the corresponding food safety supervision and management teams and inspection and testing institutions in the industry and commerce administration and quality and technical supervision departments were transferred from AQSIQ to the food and drug supervision and management departments.

To create an effective convergence of food safety supervision and management, and to clarify the responsibilities, the scheme proposed that the newly formed China Food and Drug Administration (CFDA) be responsible for food safety risk assessment and the development of food safety standards. Meanwhile, the Ministry of Agriculture is responsible for the quality and safety supervision and the management of agricultural products, as well as pig slaughter supervision and management responsibilities previously assigned to the Ministry of Commerce. The office of the Food Safety Management Commission within the State Council was dissolved.

The primary intention of the scheme is to promote the integration of food safety regulators and their responsibilities, to achieve united food and drug supervision and management, and to reduce the coexistence of regulatory overlaps and regulatory blind spots as much as possible, so that regulatory responsibilities are implemented and the level of food and drug supervision and management is further improved.

Echoing the aforementioned "Resolution on the institutional reform and functional transformation scheme of the State Council (draft)," the amendment to the Food Safety Law was launched in 2013. On 24 April 2015, the newly revised Food Safety Law was approved by the NPC Standing Committee and implemented on 1 October 2015. The 2015 edition of the Food Safety Law solidified the supervision and management system of reforms in legal form and improved a variety of institutional mechanisms on food safety supervision and management. The aims were to resolve outstanding problems in the field and to establish a severe punishment system to achieve a deterrent effected through such punishments.

In comparison with the 2009 edition of the Food Safety Law, the new law has been intensively revised, increasing the original 104 articles to 154 articles. The primary modifications have been reflected in the following nine parts:

1) The authoritative food safety regulatory agencies were improved and unified from segmented supervision and management to unified supervision and management by the China Food and Drug Administration Department.
2) Local management responsibilities were strengthened. China's food safety supervision and management system belongs to the cooperative central and local government administration system. The new Food Safety Law fully reflects these provisions, while proposing more specific and clear requirements in the following areas: The nation's food safety protection capability has been strengthened and the government is now required to enhance its protection of food safety. The new law proposes that the people's government at the county level and above must integrate food safety work into the national economic and social development plan and include funding for food safety enforcement in the fiscal budget for this level of government to strengthen the capacity of the food safety supervision and management system. The accountability of the food safety management has been implemented. The new law requires the people's government at a high level to perform a specific review and assessment role on the food safety supervision department at the local government levels. The supervision of individual workshops for food vendors has been strengthened. The new law requires local government to develop specific management provisions for individual food production and processing workshops for the food vendors. According to the newly introduced Legislation Law, there is an explicit requirement that the state authorities must make specific supporting provisions on certain matters to engage in these provisions within one year of its implementation. Accountability has been strengthened. The new law strengthens the accountability

of food safety at local government level and requires that those who do not comply with the law in terms of the reporting and handling of food safety accidents or those who fail to engage in the timely remediation of regional food safety problems involving multiple links in the administrative area will be promptly addressed. In cases of failure to establish a food safety supervision mechanism and information-sharing mechanism, the new law contains relevant provisions and sets the corresponding administrative accountability articles.

3) A stringent whole-process supervision system was clearly established. Each link responsible for the food production, the distribution, the catering services, the food marketing of agricultural products, the food additives involved in food production and management processes, the supervision of food-related products, the new industry format for networked food trading, and the management of process control in the production and operation processes were all refined and improved. This further emphasizes the subject accountability of food producers and traders and the regulatory responsibility of the regulatory authorities. For example, the new law stipulates the following provisions for Internet food trading: for third-party trading platforms that are engaged in Internet food trading, there is a requirement that the network traders need to register under their real names and management accountability is specified. The third-party Internet food trading platform provider must review the licenses of the food traders who need to legally obtain a license to operate. This is especially in case the Internet food traders violate the law in which case the platform provider must intervene promptly and stop the violation, immediately reporting the case to the food and drug regulatory authorities. When serious violations take place, the online trading platform services must be immediately stopped. The consumers that have their legitimate rights and interests infringed upon may, through a third-party Internet food trading platform, claim compensation from the networked food traders or food manufacturers. If the third-party Internet food trading platform provider cannot provide the real name, brand name, address and valid communication means of the food trader network, then the third-party Internet food trading platform provider needs to compensate the consumer. After the platform provider provides this compensation, they are entitled to recover compensation from the networked food traders or manufacturers. Also, the platform provider needs to honor its commitment to consumers, if any.
4) Prevention of food safety incidence and risk prevention has been emphasized more than before. The basic food safety systems such as food safety risk monitoring and risk assessment have been further improved and some key systems, such as accountability interviews and the risk classification management system have been supplemented, focusing on preventive measures and the elimination of hidden risks.
5) The social cogovernance of food safety has become practiced. Various aspects include giving the media and consumers full access to food safety governance in order to engage in the ordered participation in the whole food safety community and the pattern of social cogovernance. Social cogovernance is a new principle and idea, and it refers to the strengthening of food safety management in a manner that can neither rely solely on government laws nor on the regulatory authorities. All the participants must be mobilized and partake in the effort so that a joint force can be formed and an ideal food safety governance system is achieved. The new law first specifies that the basic principle of the social cogovernance of food safety should be

adopted. At the same time, this principle is embodied by four specific and systemic parts. First, the law specifies that the food industry associations have to establish and improve industry standards and incentive mechanisms in accordance with the bylaws. They must provide services such as food safety information technology to guide and supervise food manufacturers and operators on how to run their businesses in a law-abiding fashion. Second, consumer associations and other consumer organizations must engage in the social supervision of activities and behavior that may violate food safety law and they must protect the legitimate rights and interests of consumers according to the law. Third, the provisions that address the accusations and the reporting of food safety violations have been supplemented. They specify that informants with verified reports on food safety violations be rewarded. Information related to the informants should be kept confidential to protect their legitimate rights and interests. Insider informants that report their current enterprises for food safety violations should be granted special protection. Fourth, food safety information releases are regulated, and the law emphasizes that the regulatory authorities should disclose food safety information in a manner that is accurate, timely and objective. The media are encouraged to exercise supervision of public opinion over food safety violations and it is decreed that media coverage on food safety be fair and truthful.

6) The strict supervision of special food has been highlighted and the supervision of special foods such as protective food, formula foods for special medical purposes and infant formula foods have been further improved. For example, the regulations specify that a classification management system for the registration and filing of protective food products should be adopted and that the current single product registration system be changed. This system will specify a management system involving a functional directory of a protective food raw materials catalog, which would clarify the amounts of raw materials and their corresponding products. This system would also adopt the record management of the products so that the use of these raw materials meets the specifications of the protective food raw materials catalog. It specifies that the broadcast of protective food advertisements must be examined and approved by the provincial food and drug regulatory authorities. It also specifies the basis of penalties for violations of the food safety regulations for protective food raw materials. In addition, the new law makes it clear that infant formula milk powder cannot be manufactured according to the packing method, primarily because of the considerable safety risk associated with the manufacturing of infant formula milk powder by this method. First, the packaging process is prone to causing secondary pollution. Second, during the secondary packaging process, illegal additives and shoddiness can be involved.
7) The management of pesticides has been strengthened. The new law stresses stricter supervision of pesticide use and the accelerated elimination of highly toxic and high-residue pesticides. It also promotes the development and application of alternative biological products, encouraging the use of highly efficient, low toxicity and low-residue pesticides. The text specifically emphasizes that extremely toxic and highly toxic pesticides must not be used in crops that the state regulates, such as fruit, vegetables, teas and herbs. Producers who violate the regulations through their use of extremely toxic and highly toxic pesticides will be punished with detention penalties by public security agents. This is a new means of aggravated punishment that has been added to the new law.

8) The management of edible agricultural products has been strengthened. The marketing of agricultural products is included in the adjustment scope of the food safety law. With respect to a specific system, the random inspection of the wholesale market and the establishment of inspection and record systems for received edible agricultural products have been improved. The 2009 edition of the Food Safety Law assigns regulatory responsibility for the safety of edible agricultural products to the Ministry of Agriculture. The new Food Safety Law explicitly assigns the responsibility for edible agricultural product marketing to the food and drug regulatory authorities. The wholesale market is an important element for ensuring the safety of edible agricultural products at the marketing link. Implementing a sampling inspection method for edible agricultural products is an important measure of quality control where food and drug regulatory authorities can strengthen the management and control of product quality by random inspections. The primary locations for random inspection are farmers' markets and wholesale markets where the subjects of the random inspections are primarily fruits, vegetables, raw meat and aquatic products. The primary targets of the random inspections are residues of pesticides and veterinary drugs. The agricultural department is also the regulator at the source of edible agricultural products and the food and drug supervision and management departments need to strengthen their law enforcement collaboration with agricultural departments in terms of the actual practices.
9) A more stringent legal liability system has been established. Through the improvement of the legal system, the cost to illegal offenders is further increased and punishments for food safety violations are more aggravated. First, the criminal liability for food safety violations is higher. The revised food safety law has made significant reforms in the investigation and punishment of the food safety violations. Law enforcement agencies are first required to judge whether a food safety violation also constitutes a criminal offence. If it does, then the case is transferred to a public security department for investigation and scrutinized for criminal liability. If the case is not a criminal offense, then it is subject to administrative penalties by administrative law enforcement departments. There are two regulations in the new law, as follows: (i) to strengthen efforts in punishing criminals, those who have been punished with a sentence of a fixed-term of imprisonment for food safety violations are not allowed to manage food production and operation for the rest of their lives; (ii) the accountability for administrative legal liability has been strengthened. An administrative detention punishment has been added, something that was absent in the 2009 food safety law edition. In the old law, a punishment consisting of personal freedom restriction was not given to violators of the Food Safety Law. The new law adds an administrative detention punishment for repeated serious violations such as illegally adding non-food substances, using livestock and poultry that died of disease, and using extremely toxic and highly toxic pesticides. Second, the amount of administrative finesse has substantially increased. For example, those who manufacture and sell food containing added drugs or those who sell infant formula milk powder that does not meet national standards were punished by a fine of a maximum of 10 times the value of the items sold according to the previous Food Safety Law. However, the new law states that the maximum punishment is 30 times the value of the sales amount, which substantially increases the penalty for the violation. Third, penalties have been added for repeated violations. With regards to offenders who engage in repeated

and multiple violations without correction, the new law stipulates that the food and drug regulatory authorities should impose shutdowns, even revoking licenses of food manufacturers and operators who have received administrative penalties such as a fine and three warnings within a year. Fourth, penalties are added on for providers that use illegal facilities. To strengthen supervision of the source and the whole process, those who knowingly engage in the production and use of operation facilities for making unlicensed products or those who illegally add non-food substances to food products are subject to severe penalties. Fifth, the civil liability has been strengthened in a number of ways. The redress system for consumers has been added and the new law strengthens the protection of consumer rights. It requires that when food producers and operators receive compensation requests from consumers, the food producers and operators must employ the redress system and the compensation must be paid first without prevarication. Another way is through improving the punitive redress system. On the basis of a punitive redress of 10 times the sales amount, additional punitive compensation of three times the loss has been added. The civil joint liability has been strengthened. The previous food safety law gave joint liability to the sponsors of the centralized trading market. The new law requires that an Internet food trading platform provider who has failed to fulfill statutory obligations or those who have been found to be using a false food inspection report confirmed by certification institutions, and those that have infringed consumers' legitimate rights are required to shoulder joint liability with the manufacturers and the operators. The civil liability for the fabrication and spreading of false information on food safety has been strengthened. The new law requires that those who fabricate and spread false information about food safety in the media will bear compensation liability, which was absent in the previous food safety law.

21.4 The Future

"Resolutions on some key issues of the comprehensive promotion of rule of law by the Central Committee of CPC" was approved during the 4th Plenary Session of the 18th Central Committee of the CPC. This resolution proposes a strategic plan to promote the rule of law in a comprehensive manner under the new regulations. It also provides new opportunities for improving the food safety legal system and its operating environment.

Currently, China's food safety legislation system primarily uses the food safety law as the basic law, which is supplemented with various departmental regulations. The food safety legislation primarily focuses on regulatory legislation, but special legislation related to civil disputes in food safety is lacking. The judicial interpretation has not been well defined yet, resulting in some remarkable judicial difficulties. In addition, China's food safety detection, inspection and standards system is still incomplete and the overall level of implementation is low. The overlap of multiple leaders and standards still exist. The risk monitoring and assessment systems are far from perfect.

Currently, the food safety supervision system is still undeveloped, which is mainly reflected in the insufficient development of the role of law enforcement agencies, confusion about their obligations and rights, excessive attention to the interests of the various departments of the law enforcement process, avoiding responsibilities and a failure to clarify the purpose of law enforcement, which is to uphold and protect the public interest with regard to food safety. There is a lack of continuity and standardization in enforcing and normalization of the Food Safety Law. There are no forward-looking enforcement mechanisms in the unannounced inspections and treatments by the relevant law enforcement agencies after major food safety accidents. Instead, there is currently a lack of law enforcement and the penalties for violations are too lenient. The reason penalties for violations of food safety regulations are too light is because the system is mostly using fines to replace supervision and criminal penalties. This leniency leads to the prevailing low cost of violations, plus the high cost of law adhesion among food producers and traders. It is therefore difficult to contain food safety violations.

Also, the food safety production and operation units lack knowledge about food safety. Units emphasize production, but neglect hygiene due to rampant fraud and speculation. There is still fertile soil for those who wish to play the system by illegally manufacturing and selling ropey foods to seek economic benefits at perceived low risk. The legal consciousness of consumers is still inadequate. Because of the expense, time and effort involved in safeguarding rights and the difficulty of obtaining evidence, the cost of safeguarding is rather high. This results in low enthusiasm and awareness of consumer rights.

In the future, the development of the rule of law in food safety in China should be focused on the following targets:

1) *Reinforce the legislative base and improve the legal system*. First, the revisions in the supporting legal documents that pertain to food safety laws must be accelerated. First, the upgrade of the laws and regulations must occur, with the elimination of backwardness and conflict so as to enhance the balance and cohesion between the laws and regulations. Second, based on the clarification of the filing requirements and the punishment standards for criminal activities with regard to food safety, administrative enforcement and criminal justice must be linked and converged to speed up the efficiency of punishing food safety violations and to increase disciplinary intensity against these violations. Third, an external oversight mechanism must be established and improved, and grievance procedures and systems must be constructed. The people's congresses at all levels can then play a supervisory role and public representatives can participate in the decision-making and operation of supervisory institutions. Fourth, the development and the revision of food safety standards should be actively pursued to challenge the redundant parallelism of national standards, local standards and industry standards. A united standard system should be issued to replace items such as obsolete food standards, poor specificity, integrity and operability, then the lack of concentration can be resolved. Fifth, the system in which food quality standards and food hygiene standards are separated must be changed so that one organization is responsible for the formulation and revision of all standards. Other regulatory agencies can be entrusted to assist in the development of the relevant food standards and reporting duties to higher organizations [8].
2) *Strengthen the judicial relief system and improve the governance channels*. First, the convergence of administrative law enforcement and criminal justice must be clarified. Criminal actions against food safety violations should be severely punished. According to the law, the transfer procedures for cases with suspected criminals

have improved to achieve interconnection and the intercommunication of information between the law enforcement and judicial systems. Action is taken to prevent the lack of case transference, to cut down on the difficulty involved in the transfer of cases, and of the use of fines to replace criminal persecution. The administrative law enforcement departments and the judicial authorities should cooperate with one other to hold suspects of food safety crimes accountable.

Second, the civil liability of food producers and traders must be implemented to protect the legitimate rights and interests of consumers. Although there are already legal provisions to indicate that food producers and traders must bear major liability for their violations against the rights and interests of consumers, in practice the civil liability of food producers and traders toward consumers is not realized. Therefore, it is necessary to further improve the relevant litigation system, simplify the proceedings, broaden the judicial remedies, reduce the cost of safeguarding consumer rights and intensify efforts to protect consumers' legitimate rights and interests. The legal awareness of food producers and traders must be enhanced [8].

3) *Strengthen territorial responsibility and clarify the relations among compartmentalized entities.* In terms of the laws and regulations, there is a need to coordinate the relations between national laws and local legislation to a greater degree. At present, the safeguarding of food safety has dual national and regional characteristics [9]. On one hand, on the basis of an increasingly developed market economy and the formation of grids in the logistics network, the flow of food has increased drastically and has essentially no geographical constraints. On the other hand, on the basis of food cultures in different regions and imbalances in economic development, the circumstances of the food industry in different areas will vary, inevitably leading to regional characteristics in the safeguarding of food safety. In this context, local legislation must shoulder the dual functions of refining and implementing national laws and specialize in accordance with local characteristics, while bridging the gap [10]. The requirements from national laws are implemented with a focus on common food safety issues. Supplemental legislation is aimed at local and regional food safety issues without violating the national laws. In the implementation of local food safety legislation, local regulations can play a strong governing role and cure some "chronic illnesses" in the field of food safety, while providing a forceful safeguard of the health, security and life of the public. However, in applying the local legislation, the same dilemma that is encountered in the national legislation process may also emerge. For example, the new law requires the local government to develop specific management measures for individual food production workshops and food vendors. Individual food production workshops generally have a fixed production and operation site and their supervision is relatively easy. By contrast, food vendors have been more difficult to supervise because of their large numbers and easy mobility. Although the local legislation on food safety has clearly outlined the conditions, requirements, scope and certificates, and invoice systems for production and operation by food vendors, it lacks maneuverability. The regulation of food vendors has the dual challenges of food safety relative to development and food safety relative to people's livelihoods. There is an urgent need to control food safety hazards among food vendors. Food vending plays a positive role in promoting the employment of migrant workers, protecting the basic right to life of the workers and making it convenient for people to eat outside of their residence. Therefore, in the future, a more prominent

role in responding to the deficiencies and bridging the gap in local food safety legislation would provide systematic regulation on the issues with respect to local food safety supervision. It would help local legislation gain more practicality and vitality, and it would ultimately become a potential approach for local food safety legislation to achieve full effectiveness.

References

1 Wenxian Zhang. Legal system and governance modernization. *Chinese Legal Science*, 2014(4):5–27 [in Chinese].

2 Food Safety Law of the People's Republic of China [in Chinese].

3 Food Safety Law Implementing Regulations of the People's Republic of China [in Chinese].

4 Yanlin Wang. *Implementation issues of Food Safety Law of the People's Republic of China*. Beijing, Chinese Metrology Press, 2009:2 [in Chinese].

5 Agricultural Product Quality Safety Law of the People's Republic of China [in Chinese].

6 Product Quality Law of the People's Republic of China [in Chinese].

7 Criminal Law Amendment of the People's Republic of China (Eight) [in Chinese].

8 Qinghai Li, Ning Liu. Civil Law Perspective of civil law on food security issues in China. *Shenyang University of Technology (Social Science)*, 2012(4): 197–202 [in Chinese].

9 Dong Ding, Chong Chen. Study on Local Legislation of food safety. *Monocracy Forum*, 2014(27):48–57 [in Chinese].

10 Xin Liu, Gang Wang, Xiaorui Hu. Local Law of Food Safety: Practice and Experience. *Forward Position*, 2014(11):108–109 [in Chinese].

22

Food Safety Standards

Zhutian Wang[1]*, Yongxiang Fan*[1]*, Zhe Zhang*[1] *and Samuel Godefroy*[2]

[1] *China National Center for Food Safety Risk Assessment, China*
[2] *University Laval, Québec, QC, Canada*

22.1 China's Food Standards before Promulgation of the Food Safety Law

22.1.1 Chinese Food Standardization History

In the 1950s, the then Ministry of Health published the first limit on the content of arsenic in soy sauce, marking the start of China's food standards. Before the 1960s, Chinese food enterprises were generally small in size. Manual food production processes were most prevalent at the time. The "standardization" management concept sprouting in the early 1960s pushed the State Council to formulate the "Standardization Development Plan for the Period from 1963 to 1972" [1], thus kicking off the standardization of the food industry in China.

In the early 1970s, the then Ministry of Health successively completed epidemiology studies, investigation of contamination incidents and other basic research initiatives on lead, arsenic, cadmium, mercury, aflatoxin B_1 and other contaminants in food in several parts of the country [2]. In order to strengthen health management, the Health Institute under the Chinese Academy of Medical Science, subordinate to the then Ministry of Health, steered the work of nationwide experts to formulate 54 food hygiene standards in 1977, for food products that were consumed in large quantities, such as grains, oils, meat, eggs and milk, and food additives and some contaminants that were more likely to lead to food hygiene incidents, marking the birth of China's first standards with food safety objectives [3].

China established the National Bureau of Standards in 1978. In July 1979, the State Council promulgated the Regulations of the People's Republic of China for the Administration of Standardization, marking the beginning of national efforts towards standardization. In 1980, the National Bureau of Standards established the first technical committee for standardization, which was the Technical Committee for Standardization of Food Additives (code: TC11) [4], and in 1985, the National Technical Committee for Food Industry Standardization (code: TC64) was also established [4].

Food Safety in China: Science, Technology, Management and Regulation, First Edition.
Edited by Joseph J. Jen and Junshi Chen.

In 1988, China promulgated the Standardization Law, which stipulated that standards must be formulated for "the category, specification, quality, class or safety of industrial products". Food, as an industrial product, thus required regulations on its category, specification, quality and other aspects in order to keep the product up to its deserved quality requirements. The Standardization Law also stipulated that "standards for safeguarding human health and ensuring the safety of the person and of property and those for compulsory execution as prescribed by the laws and administrative rules and regulations shall be compulsory standards, the others shall be voluntary standards". The law therefore enabled the development of both compulsory (food safety) standards as well as other voluntary food standards. In accordance with the requirements of the Standardization Law and its implementation rules, the food standardization work has proceeded gradually and in an incremental manner. In addition to compulsory food hygiene standards, China formulated and published a series of standards related to food quality.

With the constant advancement of certification and accreditation work, the last decade of the twentieth century witnessed a vigorous growth in the certification of green food, organic foods and products with specific geographic indications. To adapt to this, a large number of standards related to green food, organic food, pollution-free food and foods with specific geographic indications were developed and now constitute an important part of the Chinese food standards system.

According to the website of the Standardization Administration of China, China currently has 31 nationwide technical committees for standardization related to food, covering a wide range of fields, including food industry, food additives, food packaging, food labels, snack food, instant food, bakery products, confectionery and chocolate, and so on. Moreover, there is also a variety of standards management and formulation agencies specific to food-related industries such as light industry, commerce, domestic trade, import and export, agriculture, and forestry [1]. This, on one hand, has significantly pushed the development of standardization of the food industry, and on the other hand, has caused serious problems such as excessive standards, possible duplication and contradiction between these standards.

22.1.2 Development of Food Hygiene Standards

The Chinese Food Hygiene Standards are an integral part of the food standards and have been solely managed by the health administrative department of the State Council. In August 1979, the State Council promulgated the Regulations of the People's Republic of China for the Administration of Food Hygiene, which explicitly put forward the concept of food hygiene standards and stipulated that "all food sold must be clean and free from poisons, pathogenic germs and viruses, parasites, deterioration, mildew, and foreign matter and must be good for and do no harm to the people's health. The health departments and related competent departments shall gradually formulate hygiene standards and inspection methods for all kinds of food, food materials, food additives and food packing materials (hereinafter referred to as 'Food Hygiene Standards') through common research based on the above principle." [5]

In 1982, the Food Hygiene Law of the People's Republic of China was published (for trial implementation) and further affirmed the legal status of the Food Hygiene Standards. The Law stipulated that "The administrative department of public health under the State Council shall formulate or approve and promulgate the national hygiene standards, hygiene control regulations and inspection procedures for food, food additives, food containers, packaging materials, utensils and equipment used for food, detergents and disinfectants used for washing food or utensils and equipment used for food, and the tolerances for contaminants and radioactive substances in food." [6] The Ministry of Health subsequently set up several technical sub-committees for food hygiene and other standards, and systematically organized the research and formulation of food hygiene standards, as well as the underpinning studies and research, such as the detection and monitoring of food-borne diseases and the analytical methods, whether physicochemical or microbiological, targeting food contaminants, biotoxins, food additives, nutritional fortification substances, food containers and packing materials, and irradiated foods.

In 1984, China officially became a member state of the Codex Alimentarius Commission (CAC) and formed a China Food Codex Coordination Group composed of the Ministry of Health and the Ministry of Agriculture with the Ministry of Health serving as group leader, marking China's official participation in the international system for setting food standards [7].

After the promulgation of the Food Hygiene Law of the People's Republic of China, under the organization and leadership of the Ministry of Health, a plan was developed and implemented to formulate in a considered and systematic manner a series of food safety and hygiene standards. In 1984–1985, this plan resulted in the promulgation of 28 analytical methods targeting microorganisms (GB 4789-1984) and 75 physicochemical (GB 5009-1985) analytical methods. In 1994, a toxicology safety assessment procedure and methodology was also developed under this plan (GB 14193-1994).

Over time, the food safety and hygiene standards underwent at least three rounds of major cleanup and reorganization, to make them more up to date with new findings and recent developments. During the period from 1990 to 1991, several meetings of group leaders for national food standard formulation were held to organize and implement the cleanup and reorganization of standards related to edible ice, ice cream and cold drinks, rubber products, packaging materials, edible vegetable oil, alcoholic beverages, seasoning, dairy products and food additives. Experts also aimed to review, classify-and-merge or revoke standards that have existed for too long a time and which did not adapt to the development of Chinese society.

As a follow-up to China joining the World Trade Organization (WTO), the Ministry of Health carried out in 2001 [8] and 2004 [9] detailed comparative analyses between Chinese standards and standards formulated by the CAC. The Ministry re-evaluated standards that were deemed to be inconsistent with international standards and revised and adjusted other standards to account for the dietary patterns of Chinese residents. These two rounds of standards review and cleanup did not only improve the level of Chinese food standards but also aligned Chinese national food standards with international food standards.

22.1.3 The Food Hygiene Standard System Forms the Predecessor of Food Safety Standards

22.1.3.1 Formulation of Food Hygiene Standards

The research and formulation of food hygiene standards was mainly undertaken by the Health Institute of the Chinese Academy of Medical Science. Working groups made of experts from the sanitation, public health and epidemiology centers, such as Centers of Disease Control, of each province carried out food hygiene standard research and formulation with support from national authorities at the central level. After its founding, the Expert Sub-Committee of Food Hygiene Standards under the National Technical Committee for Standardization started to regularly carry out the development of annual plans and medium and long-term plans in relation to food hygiene standards. The Expert Sub-Committee of Food Hygiene Standards held a general election every five years and an annual meeting every year.

The Food Hygiene Standard Working Group was set up and included representatives from national disease prevention and control and health supervision agencies, scientific research institutes, universities and colleges, food industry associations and food manufacturers. An extensive representativeness was sought through the inclusion of expertise from organizations with a focus on food hygiene and quality inspection, as well as the agricultural sector, food enterprises and industry associations. Once a standard was developed and drafted through the scientific input of experts, it would be submitted for input from a larger representation of society.

An additional step was also added to account for China's obligations as a member of the World Trade Organization (WTO). Food standards are therefore reported to other WTO members according to WTO/Sanitary and Phytosanitary (SPS) treaty requirements.

Once a draft standard solicited and received extensive input, it would be then submitted to the Expert Sub-Committee of Food Hygiene Standards for review. In July 2008, "The Sixth Expert Committee of Food Hygiene Standards of the Ministry of Health" was set up. In order to organize and strengthen the food hygiene standard work, the Committee set up six sub-committees and special working groups in relation to contaminants, microorganisms, pesticide residues, nutrition and special diet food, food products and hygiene regulations, food containers and packaging materials, with a total of 142 committee members [10]. This setup was the latest food hygiene standard committee before the promulgation of the *Food Safety Law*, and has resulted in the construction of a robust framework for setting up the National Committee for Food Safety Standards in the future.

At the beginning of the formulation of food hygiene standards, risk analysis and evaluation was not described in detail, but the principle of risk evaluation was implicitly applied in the course of the standard formulation and review. Scientific foundations for food safety standard formulations were developed in an incremental fashion. Results from the Chinese total diet study, as well as targeted food surveys to track food-borne contaminants, consumption and nutrition surveys started building the foundation of evidence-based food risk analysis processes. Similarly, the output of the national food contaminants monitoring network, built in 2000, as well as the food-borne disease monitoring network built shortly thereafter, helped gather a wealth of data in support of risk evaluation and therefore in support of the formulation and revision of food hygiene standards. Other criteria and considerations were also accounted for in the formulation of these standards and included the ability of the food industry to follow such standards and their practical implementation, as well as their enforceability. This approach helped shape a direction for food safety risk management.

22.1.3.2 Composition of the Food Hygiene Standards System

Before the promulgation of the Food Safety Law of the People's Republic of China in 2009, the food safety standard system was mainly composed of horizontal standards, product standards, codes of hygiene practices, and testing and inspection methods (including standards for diagnostic methods), which basically covered all kinds of health and safety indicators relating to health hazards potentially occurring in food (including edible agricultural products) from raw materials to processed final products.

There were a total of 454 food hygiene standards at that time, including eight horizontal standards, standards for contaminants in food, mycotoxins, food additives, pesticide residues, food packaging materials etc.; 128 product standards involving various foods and food-related products like food of animal and plant origins, irradiated food, disinfected tableware, packaging materials etc.; 275 inspection and testing method standards, which included 219 physicochemical testing methods, 35 standards for microbiological methods and 21 toxicological safety evaluation procedures and methods; 22 codes of hygienic practices, including general hygienic regulations of food production enterprises and good manufacturing regulations; and 19 standards for diagnosis of food poisoning or food-borne diseases. All of these formed a food hygiene standard system matching the food sanitation law.

Over time, the food hygiene standard system evolved and adapted to avoid multiplication and enhance efficiency. Standards have been combined into horizontal requirements, when they are applicable to more than one food commodity. They were also more scientifically driven and simpler to follow, allowing for easier implementation. For example, after a substantial review and revision work in 2004, several standards governing pesticide residues in food, contaminants and fungal toxins have been adjusted and consolidated into one standard for each type of contaminant. Dozens of food product hygiene standards have been reduced to about ten items. The food product standards basically covered most food hazards for raw materials and products from farm to table, and covered hygienic requirements for most foods in each step of the processing and handling.

22.1.4 Problems Related to the Parallel Existence of Various Food Standards

From the 1950s to 2008, food standards development has been conducted from scratch, and experienced an evolution from fragmentation to systematization. Before issuance of the Food Safety Law in 2009, China had more than 2000 national standards, 2900 industrial standards and 1200 local standards relating to food, food additives and food-related products, basically establishing a food standard system with national standards as the core, and industrial standards, local standards and enterprise standards as annexes. Food standards have been greatly improved in both quantity and quality, which facilitated the development of the food industry sector, provided a stronger basis for supervision and management, and better guaranteed the protection of consumers' health. However, the increase in the number of food standards, the issue of repetition and possible overlap or contradiction between standards also became increasingly prominent.

22.1.4.1 Ambiguous Boundaries Between Food Quality and Food Safety Standards

From the perspective of safeguarding consumers' health, all food should be safe. Safety should be guaranteed to all consumers regardless of their social or economic status. However, food quality can vary and can be subject to market principles. Government responsibilities include not only ensuring food safety, but also enabling fair market rules. Different authorities should govern each of these responsibilities.

The possibility of various food standards being formulated and promulgated under various authorities, compulsory national standards developed by government authorities, industrial standards developed by industry itself across a supply chain and even sometimes local and departmental standards, can lead to confusion amongst industry operators as to what needs to be complied with. It can also lead to possible confusion amongst authorities responsible for enforcement.

Through collation and analysis of food standards, it was identified that the compulsory standards, whether national or industrial, accounted for one-third of the total number of food standards. It was also identified that nearly 50% of national standards for food, food additives and food-related products were compulsory. Many of these standards were, however, deemed to be quality requirements having nothing to do with safety and health. This situation was identified as a key driver leading to confusion amongst food operators and the food industry, impacting on their compliance with these rules.

At the technical level, there were even discussions as to whether a food hygiene provision should be included in a food quality standard and vice versa. In some instances, co-mingling food safety requirements with food quality provisions may have led to contradictions, given the lack of or limited scientific basis for some of these quality requirements, which often relied more on experience.

22.1.4.2 Managing the Interface and Possible Overlap Between Industry Standards

Standards administered under a centralized management by different departments, especially industry standards, play different roles in different fields, depending on the various laws and regulations under which they are set, and also based on government ministries' management needs and requirements.

The Measures for the Administration of the Formulation of Industry Standards stipulate that industry standards refer to standards formulated in the absence of national standards and where unified technical requirements are needed for a certain industry. These industry standards must not, however, be in conflict with national standards. Industry standards are in fact meant to remain harmonized and unified and must not lead to duplication.

However, the analysis of a variety of industry standards for food identified multiple instances of overlap between such standards. This is partly due to the lengthy food production and processing chain, which may lead to the development of standards at a certain point in the chain that do not account for another point, set at a distant level from the first one, in the food processing chain.

China has established codes for food-related industry standards as follows: light industry (QB), trade (SB), agriculture (NY), aquaculture (SC), forestry (LY), grain (LS), supply and marking (GH), packaging (BB), chemical industry (HG), etc. As a result, the same food commodity may be managed through several standards leading to possible overlap and contradictions.

For example: 18 standards have been published for pork by the Ministry of Health, the Ministry of Agriculture, the Ministry of Industry and Information Technology, the

Ministry of Commerce and other relevant departments; 16 standards for beer by relevant departments; 25 standards were promulgated for liquor, which involved light industry, geographical indication products, green food and other standards; six standards were set for biscuits; and 17 standards were identified for nuts. Overlap and contradictions between these standards were identified. As a result of the multiplication of standards, there are several testing methods that were also warranted by the various standards. As an example, 25 testing methods were identified for chloromycetin throughout the various standards, 17 for penicillin, 9 for oxytetracycline and 21 for tetracyclines. Moisture content determination was prescribed through no less than 27 methods, and there were at least 4 acid value detection methods, and 25 ash detection methods.

The review of these industry standards also identified at least four specifications for egg products, 10 for livestock and poultry and six for meat products [11].

Given that this industry standards system drew its reference from the ISO standards management model with the intent to operate under a fee-for-service approach, several standards were not easily accessible and were only made available to food operators upon the payment of prescribed fee. As a result, several of these standards were not broadly disseminated and their implementation remained limited.

22.1.4.3 The Scientific Foundation of Food Hygienic Standards was Deemed to be Weak

Before the development and enacting of the 2009 Food Safety Law, China's food safety system did not rely upon an established food safety risk monitoring approach, nor was it compelled to consistently conduct risk assessments as part of its food safety standards formulation methodology. Some monitoring and assessments had been carried out in relation to some food contaminants, food additives and other relevant fields. However, the consistent application of the risk analysis approach, including the risk assessment and risk management concepts, was not systematically followed in the formulation of food hygiene and other food safety standards. A number of standards were either the outcome of measures taken as a follow-up to incident management and to associated punctual enforcement actions taken or were simply a copy of standards adopted by other trading partners, as well as by the Codex.

Therefore, the scientific foundation of these standards and their relevance to China's national context could not be systematically demonstrated. This resulted in the potential for China's food standards to be challenged by other WTO partners, either as part of bilateral or multilateral trade discussions or in the context of the WTO/SPS regular meeting discussions. Improving China's ability to meet the WTO/SPS requirements in formulating food safety standards was a subject of focus from 2005 to 2009. During this period, the former Ministry of Health carried out discussions and bilateral cooperation with various trading partners, like the United States, Canada and the European Union, and leveraged these efforts to apply the risk analysis approach and update several food safety standards such as *Salmonella* in poultry products, various contaminant standards and maximum limits in cereal products, and the maximum limit for copper in chocolate products. These standards were reformulated following science-based assessments, which helped ensure better protection of Chinese consumers' health, and alignment with international processes for food setting standards.

22.2 Setup and Development of the Food Safety Standard System

22.2.1 Setup of the Food Safety Standard System

The Food Safety Law of the People's Republic of China enacted in 2009 introduced the concept of "food safety standards" and stated that they are composed of national standards and local standards. The law also clearly stated that the food safety standards constitute the only enforceable set of food standards in China. It granted to the standards the character of technical regulations used to manage and mitigate various hazard factors in food, which have the potential to affect the health of consumers.

According to the provisions of the Food Safety Law, the national food safety standards are made up of the following eight parts:

1) Limits of pathogenic microorganisms, pesticide residues, veterinary drug residues, biotoxins, contaminants (heavy metals, etc.) and other substances that may be hazardous to human health and that can be found in food, food additives and other food-related products;
2) Approved food additive requirements including scope of application, and dose of approved food additive uses;
3) Requirements for nutritional ingredients in staple and supplementary foods dedicated to infants and other specific populations;
4) Requirements for labeling measures, such as label markings and instructions relevant to food safety requirements associated with food hygiene and nutrition, etc.;
5) Hygienic requirements related to food production and food trade;
6) Quality requirements associated with food safety;
7) Methods and procedures for food testing that relate to food safety; and
8) Other items necessary for developing food safety standards.

To help map the way the national food safety standards operate, their eight parts are in fact collected in four broad categories:

1) General standards are mainly found in Parts I, II and IV;
2) Product standards are mainly contained in Parts I, III, VI, VIII;
3) Food production and management standards are described in Part V; and
4) Standards pertaining to inspection procedures and testing methods are described in Part VII.

The general standards include the provisions related to maximum levels of pathogenic microorganisms, pesticide residues, residues of veterinary drugs, heavy metals, contaminants, including mycotoxins and other food-borne natural and environmental contaminants, standards for the use of food additives and additives used in food contact materials, and provisions on label requirements, and so on.

The product standards include provisions for food, food additives and food-related products. When the provisions in the general standards apply to any product standards, a note of reference should be made in the product standard accordingly. The product standard would then only include specific provisions, criteria, specifications and other requirements that are not covered by the general standards and that apply only to the product in question.

The third category of standards is requirements for food safety control measures and criteria throughout the production and trade of food. This category of standards includes sanitary requirements for food operators, including the design of the food production facility, requirements for organization of work, staff training, sanitary practices, product traceability and recall procedures.

The last category of standards focuses on inspection and analytical testing methods used for enforcement purposes, including physicochemical, microbiological and toxicology testing methods, and procedures relevant to food safety requirements.

22.2.2 The National Food Safety Standard Formulation Process

The People's Republic of China Food Safety Law has also defined the conditions under which the "national food safety standards" are developed. Food safety standards are formulated by the National Health and Family Planning Commission (NHFPC) (formerly the Ministry of Health) and reviewed by the National Committee for Food Safety Standards, before being published, after approval of the NHFPC.

A Secretariat of the National Committee for Food Safety Standards was established and has prepared a Procedural Manual defining the steps and procedures of the national food safety standards elaboration process.

The formulation and revision of the national food safety standards are generally composed of eight steps: programming and planning, project approval, drafting, comments collection, review, approval, re-evaluation and revision [12]. The steps in the national food safety standards development and elaboration process are presented in Figure 22.1, and are described in more detail below.

22.2.2.1 Engagement on Food Safety Standards Programming and Planning

The NHFPC and the relevant departments under the State Council are responsible for the formulation of national food safety standards programs and their implementation plans. These departments may make proposals for the formulation and revision of national food safety standards, to be submitted for approval, prior to each annual cycle of planning. Stakeholder engagement is also sought at this stage and any citizen, legal entity or organization is able to put forward suggestions pertaining to food safety standard formulation, as part of the "national food safety standards".

22.2.2.2 Planning for Standards Elaboration and Revision

The National Committee for Food Safety Standards is entrusted with reviewing all proposals for food safety standards formulation, including conducting the relevant research and providing the associated expert advice to the NHFPC, to pursue the food safety standards formulation, amendment or otherwise.

The NHFPC will also solicit input from stakeholders and the public on the proposed programming and planning of national food safety standards. The annual plan for the national food safety standards formulation and revision is therefore achieved based on the expert advice of the National Committee for Food Safety Standards and input provided by all stakeholders and members of the public representing Chinese society.

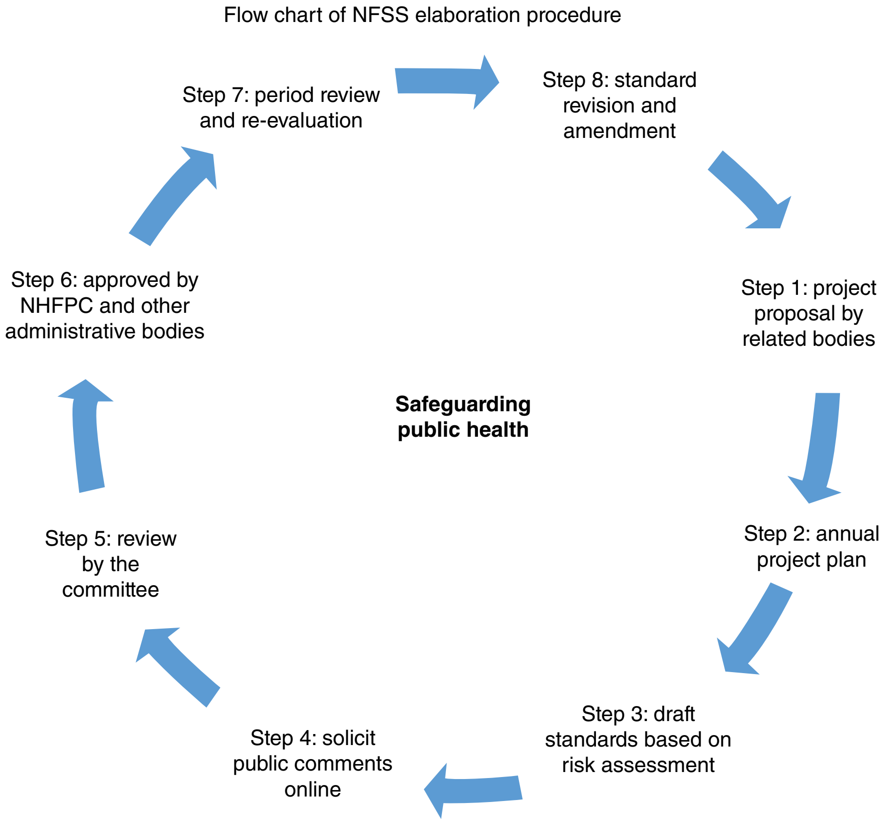


Figure 22.1 Flow chart of the national food safety standards elaboration procedure.

22.2.2.3 Drafting the Standards

It is the NHFPC's responsibility to identify the relevant unit with the qualifications and competencies required and task it with the development and drafting of the selected standard. The unit undertaking the project proceeds with the in-depth investigation and research to generate the data needed for the development and drafting of the targeted standard. In doing so, NHFPC experts follow the risk analysis approach advocated by international best practices. The standard formulation process also considers China's social economic development level and environment. The formulated standard is also developed taking into account relevant Codex standards and work conducted by other international food regulators.

22.2.2.4 Soliciting Opinions from the Public

Upon completion of the drafting step, the unit in charge of the project proceeds with soliciting input, in writing, from various government organizations in China, academic institutions, industry, enterprises, consumers, experts, supervision departments and other relevant agencies. Upon completion of a preliminary review, the draft standard is published on the website of the NHFPC for a formal solicitation of comments for a period of two months. The National Food Standards Secretariat at the NHFPC will then submit the collected feedback to the unit tasked with the standard formulation, which then focuses on addressing the comments received either by considering proposed changes to the standard or to document the reasons for not changing the proposed standard based on the input received.

22.2.2.5 Reviewing the Standards

The relevant expert sub-committee of the National Committee for Food Safety Standards is responsible for reviewing the scientific validity and practical application of the standards. The standards will be deemed to pass the review upon receiving the concurrence of more than three-quarters of the committee members participating in the review process. The expert sub-committee documents in writing the rationale of the review and makes suggestions for possible modifications. An updated standard based on the suggestions and recommendation made would be resubmitted for review. Standards passing the review by the sub-committee shall, after having the review comments signed by the Chairman of the Expert Sub-committee, be submitted for review and oversight by the National Committee of Food Safety Standards.

22.2.2.6 Approval and Issuance of the Standards

Standards are reviewed by the National Committee on Food Safety Standards and upon gaining approval are issued by the NHFPC and other administrative bodies in the form of a notice. Within 20 working days after the date of issuance, the standards will be published on the website of the NHFPC.

22.2.2.7 Tracking and Re-Evaluating Standards

The NHFPC seeks input from provincial health departments and relevant organizations to track and evaluate the implementation of the issued food safety standards. Any citizen, legal entity or other organization may put forward opinions or suggestions on any problems emerging from the standard's implementation.

22.2.2.8 Amending and Reviewing the Standards

Should there be a requirement to amend or adjust the national food safety standard, shortly after it was issued, the NHFPC would issue a notice of the modification. The National Committee for Food Safety Standards is entrusted with reviewing the standards or making recommendations for their revision or cancellation. National Food Safety Standards that need to be revised are included in a plan for food safety standards revision, to be submitted for approval by the NHFPC.

22.2.3 Gradual Development of the National Food Safety Standard System

The newly promulgated Chinese *Food Safety Law* stipulated that the health administrative governmental body under the authority of the State Council integrate the compulsory standards among existing quality and safety standards for edible agricultural products, food hygiene standards, food quality standards and industry standards relevant to food. Food producers and traders were asked to continue to comply with the original standards, prior to the issuance of the national food safety standards.

The cleanup and integration of food standards started in an orderly manner by priority and stages in 2008. During the period from 2008 to 2010, according to the requirements of the Regulations for the Supervision and Administration of the Quality and Safety of Dairy Products and the Outline for the Reorganization and Development of the Dairy Industry promulgated by the State Council, more than 160 standards related to dairy products were cleaned up, and made into 66 standards on the quality and safety of dairy products [13].

During the period from 2010 to 2013, the cleanup and revision of the main general food safety standards were completed; and a series of general standards, including the Standards for the Use of Food Additives (GB 2760), Maximum Levels of Mycotoxins in Foods (GB 2761), Maximum Levels of Contaminants in Foods (GB 2762), Maximum Levels of Pathogenic Microorganisms in Foods (GB 29921), Standards for the Use of Nutritional Fortification Substances in Foods (GB 14880), General Standards for the Labeling of Prepackaged Foods (GB 7718), General Standards for the Nutrition Labeling of Prepackaged Food (GB 28050) and General Hygiene Standards for Food Production (GB 14881), etc., were published [14]. During the period from 2009 to 2013, more than 3000 substances intended for use in food packaging materials were cleaned-up and the revision of the Standards for the Use of Substances in Food Contact Materials (GB 9685) was launched, which has laid a good foundation for the overall cleanup of food standards [15].

In 2013, the overall cleanup of food standards was formally initiated. The Secretariat of the National Committee for Food Safety Standards collected and sorted out 4934 quality and safety standards for edible agricultural products, food hygienic standards, food quality standards and relevant industry standards, and carried out an evaluation of the possible cleanup on a standard-by-standard basis, according to the deployment of the Plan on Food Standards Cleanup [16]. The Secretariat put forward a framework for the national food safety standard system covering over 1000 national food safety standards. The NHFPC developed a work program for the Integration of National Food Safety Standards [17] for 415 standards that were included in the national food safety standard system, but not identified in any approved annual plans. The integration work was conducted in an orderly manner and was completed in December 2015. By the end of April 2016, 683 national food safety standards were issued.

22.2.4 China Strengthens its Contribution to the Formulation of International Food Standards

China has been increasingly active in the international process for setting food standards, while carrying out the development and update of its own national food safety standards.

China has acted as the host country of the Codex Committee on Food Additives (CCFA) and the Codex Committee on Pesticide Residues (CCPR) since 2007. China also served on the Executive Committee of the Codex Alimentarius Commission as a member for Asia in 2010. By hosting the CCFA and the CCPR, Chinese experts were able to learn from the experience and the step-based approach followed in the formulation and management of international food standards.

In addition, China continued its contribution as an active member of the WTO and fulfilled its obligations by notifying members of new food safety standards being developed as per the requirements of the SPS agreement. China also continued its active cooperation with other members of the WTO in areas pertaining to food standards development, towards enhancing the scientific foundation and the transparency of the standards development process.

Since 2009, China has published and promulgated more than 600 technical regulations on food safety and actively considered and responded to comments and input from members of the WTO.

22.2.5 Challenges to Continuing to Enhance China's Food Safety Standards

The existing food safety standard system continues to face some challenges that need to be addressed, specifically in view of current food industry development and the capacity of food safety risk assessment.

1) *The scientific foundation and practical application need enhancement*: The scientific data required to conduct health risk assessments in support of standard development continue to be lacking in a number of areas. Data supporting exposure evaluations related to China's national context need to be generated in a number of fields. Investment in health risk assessment capacity needs to be continued.

   The cursory review of China's current food safety standards identified that about 40% of the standards set are replicas of international standards or requirements put forward during the period from the 1980s to the 1990s [18]. The integration of the national food safety standards has been a heavy task and had to be completed over a short period. This has resulted in focusing more specifically on efforts of integration and avoidance of duplication rather than conducting a fulsome review of each of these standards. This has also led to keeping the same levels/requirements as previously used standards. A more in-depth review of some of these food safety standards needs to be undertaken to ensure that they are based on Chinese health risk assessments and that they are also reflective of China's food production practices.
2) *There remain some inconsistencies among food safety standards*: The national food safety standard system covers general standards, product standards, codes of practices, and testing and inspection methods. There are, however, some inconsistencies within the system, and between the system and other food-related standards, which may affect industry's understanding of their level of accountability and the requirements that need to be met. In effect, the product standards in the system are not always consistent with the food classification systems adopted for general standards. Similarly, the food classification regime does not match the food production license application system. This may have an impact on the implementation of the standards and will need to be addressed.
3) *Evaluating the socio-economic impact of food safety standards is at its initial stage*: During the formulation of national food safety standards, more efforts should be made to assess the impacts of the proposed standards, such as the economic and social costs of implementation by industry as well as costs associated with enforcement.
4) *More efforts are required to support risk communication associated with the promulgation of food safety standards*: The main users of food safety standards are the enterprises engaging in food production and marketing and governmental bodies in charge of supervision and enforcement. The formulation and implementation of

food safety standards are, however, relevant to all sectors of society. Food enterprises, scientific institutions, food supervision and enforcement organizations, academic groups and consumers are stakeholders impacted by food safety standards development work. Changes in science and technology, in consumer interests and in enforcement requirements make it necessary to work towards continued improvement of the food safety standard management system and work procedures. This includes enhancement of stakeholder engagement and solicitation of input, as well as promotion of and communication about the developed and implemented food safety standards.

22.3 Future Directions and Trends in Food Safety Standards Development

On April 24, 2015, the Food Safety Law of the People's Republic of China [19], which was amended over two years, was enacted. It became enforceable in October 2015 and will continue to safeguard consumers' health in China from food safety hazards. The contents of Chapter III "Food Safety Standards" in the amended Law have also been changed, which will directly affect the way future food safety standards will be developed and will operate.

22.3.1 Future Directions of Food Safety Standards Development

22.3.1.1 Departmental Coordination of Food Safety Standards will be Further Strengthened

The State Council carried out a reform of the super ministry system in 2013, with the aim of improving the requirements of "shared governance by various government bodies". The supervision function on food safety in China is to be exercised by the China Food and Drug Administration (CFDA).

The amended Food Safety Law stipulates that standards for pesticide and veterinary drug residues, as well as their methods of analysis and inspection will be the responsibility of the NHFPC, the CFDA and the Ministry of Agriculture. The law also stipulates that the NHFPC will develop and issue other national food safety standards, together with the CFDA. The health and agriculture administrative departments under the State Council will also establish a mechanism for communication and coordination with the CFDA and the Quality Supervision Department under the State Council regarding the standards. The Health Administrative Department and Food and Drug Administration under the State Council will establish a joint mechanism for formulation and issuance of standards, effectively sharing food safety supervision spot check data and risk monitoring data and collecting opinions and suggestions from various food safety supervision departments, to ensure that food safety standards meet the needs of food safety supervision, both domestically and for foods imported to and exported from China. The Agriculture Administrative Department under the State Council will accelerate the formulation and issuance of standards related to pesticide and veterinary drug residues and relevant methods of analysis and inspection, and complete the link between edible agricultural products quality and safety standards and the national food safety standards.

22.3.1.2 The Scientific Foundation for Food Safety Standards will be Further Strengthened

The Food Safety Law further emphasizes that the country will establish a system for risk monitoring and will improve its risk assessment capacity. The law reiterates the importance that national food safety standards be formulated based on the results of scientific and health risk evaluations of food and edible agricultural products and in consideration of relevant international standards, as well as results from other international food safety risk assessments.

As a result of the improvement of the national food safety risk assessment agency and gradual enhancement of competencies and capacity to conduct risk assessments in support of standard development, the formulation of food safety standards has become increasingly based on the outcomes of robust risk assessments, which strengthen the ability of the formulated food safety standards to safeguard China's food supply.

22.3.1.3 Tracking Assessment, Promotion and Training on Developed and Adopted Standards will be Enhanced

There is a need to ensure a follow-up on food safety standards formulation efforts to track their implementation and the way they are received by various food actors and stakeholders. The Food Safety Law directs enhanced promotion and follow-up after issuance of food safety standards. The Law stipulates that health administrative departmenta at the provincial level and above, together with the Food and Drug Administration, the Quality Supervision Department and the Agriculture Administrative Department at the same level, track and evaluate the implementation of national and local food safety standards. This tracking and follow-up should be based on the situation on the ground for the corresponding jurisdiction and should include promotion and training related to the targeted standards, as well as collection of opinions, feedback and suggestions on challenges related to their implementation. This should support the timely amendment of the standards, based on the results of such evaluations.

To carry out the requirements of follow-up and tracking of the implementation of food safety standards, China's National Center for Food Safety Risk Assessment (CFSA) [20] established a platform for collection [21] of feedback, suggestions and opinions on national food safety standards. The CFSA also supports the expert review and analysis of input, suggestions and recommendations provided and puts forward the relevant proposed changes to the competent department for consideration in a timely manner. In addition, the CFSA is developing research to enable the assessment of socio-economic impacts related to the implementation of national food safety standards to support robust risk management approaches to food safety risks.

22.3.1.4 The Standard Formulation Process will be More Open and Transparent and Embody the "Shared Governance by all Stakeholders" Approach

The Food Safety Law calls for adopting the principles of "putting prevention first, risk-based management, whole-process control, and making efforts to embrace a shared governance by all stakeholders". By adopting the "shared governance by all stakeholders" approach, all sectors of society are made aware of the importance of food safety; consumers, social organizations and third parties are all to be part of the food safety governance system. This will in turn, help develop a social and broad governance network system for food safety, covering government, social organizations, third parties and consumers. Draft standards are to be issued to the public to solicit opinions and input from food producers and traders, consumers and relevant departments. At each step of the food safety standards formulation and amendment process, opinions from all sectors of society are collected in a timely fashion using a web-based platform. Active participation by interested parties should be promoted. Apart from the involvement of all domestic stakeholders, China's membership in the WTO has also led to timely information and notification of other WTO members about the formulation of new food safety standards, seeking their input and comments, as relevant, and presenting the scientific foundation of the adopted measures where appropriate.

22.3.2 Challenges Faced by Food Safety Standards Formulation

It is foreseeable that in the context of the current development of the Chinese food industry and the food safety supervision capacity, a number of challenges will be witnessed over the coming period:

1) *Ensuring effective use of food safety standards in enforcement and food safety supervision.* As a risk management measure, food safety standards are the backbone of food safety supervision efforts, but do not represent all food safety efforts. The national food safety standards focus on applying general requirements to solve food safety issues, while the enforcement bodies expect more detailed, and more directive and prescriptive rules to follow on each specific case. Therefore, there will be a running-in period to build dialogue and effective collaboration between the NHFPC and the CFDA to ensure optimum coordination of food standards development and implementation. A balance needs to be struck between the development of flexible outcome-based standards, underpinned by a robust scientific foundation and the need to ensure a predictable and practical environment for implementation of food safety standards for both industry and government enforcement bodies such as the CFDA. The food safety supervision approach needs to rely upon a whole-system preventive approach and to move away from relying heavily on final product testing and prescriptive sets of product-by-product requirements.
2) *There continues to be overlap between food safety standards and other food standards.* Various food quality standards and food industry standard systems managed by the SAC exist with a wide scope and continue to guide food industry. The continued elaboration of these standards with limited coordination or engagement with the food safety standards development process may lead to perpetuating the duplication and contradiction between various food standards requirements. The use of the common terminology of "standards" and the absence of clarity as to what is mandatory and what is recommended contributes to possible confusion on the part of industry and food producers. There may be a need to develop a clear distinction, through formal technical regulations where all the mandatory standards are clearly distinguished from voluntary recommendations in the overall Chinese standard setting environment.
3) *The role played of food safety standards in preventing and mitigating food fraud needs to be clarified.* Recent incidents related to honey adulteration raised a broad level of social concern and posed the question of the role played by food safety standards in preventing such food fraud. With continuous amendments to mandatory and recommended honey standards, the role of the national food safety standards in

terms of controlling quality requirements has to be further clarified. The European experience of addressing the recent horsemeat crisis or Canada's experience in managing specific commodities, such as maple syrup, using food safety and quality standards and the way in which they interact could serve as examples to support future evolution of the food safety and quality system in China.

22.4 Conclusion

Over the last two decades, China's national food safety standards system has witnessed considerable changes and reform. The recent adoption of the Food Safety Law and efforts made to update, clean up and modernize food safety standards development and formulation in accordance with international best practices have set a robust foundation for future work. Newly established accountabilities and governance systems are being developed and implemented between various government bodies, such as the CFDA, the NHFPC, the Administration for Quality Supervision, Inspection and Quarantine (AQSIQ) and the MOA, as major actors in China's national food safety system. The effective coordination of efforts between these partners and the continued engagement of stakeholders will be key to ensuring a flexible, adaptable and responsive food safety standards system.

References

1 Food Standardization, formulated by the Department of Agriculture, Light Industry and Local Standardization Division of Agriculture under the Standardization Administration of China, 2007, China Standards Press.

2 Li Xiaoyu, The status quo and development trends of China's Food Hygiene Standard. *Food Science*, 2006, 27(9): 275–277.

3 Fan Yongxiang, Zhu Lihua, Wang Jun, et al. Progress of China's Food Hygiene Standard after 30 years of reform and opening up. *Chinese Journal of Food Hygiene*, 2009, 21(4): 312–315.

4 Hao Yu, Chinese food industry standardization development history. *China Standardization*, 2001, 1(7): 8–9.

5 Regulations of the People's Republic of China for the Administration of Food Hygiene: http://www.cnki.com.cn/Article/CJFDTOTAL-ZYZZ198002000.htm (accessed November 2016).

6 Food Hygiene Law of the People's Republic of China (for trial implementation), http://www.npc.gov.cn/wxzl/gongbao/2000-12/06/content_5004417.htm (accessed November 2016).

7 Liu Xiumei, National and international food safety control system. *Global Food Industry*, 2004, (4): 52–53.

8 Tian Jinghua, Han Yulian, Li Xiaoyu, et al., Analysis of national food hygiene standard cleanup and examination result. *Chinese Journal of Health Inspection*, 2004,11(2): 90–93.

9 2004-2005 Food Standard Development Plan, National Development and Reform Commission, Ministry of Agriculture, Ministry of Health, Ministry of Commerce,

AQSIQ, CFDA, Standardization Administration of the P.R.C., China National Light Industry Council, China General Chamber of Commerce.

10 Ministry of Health held the 6th session of the Food Hygiene Standards Expert Committee, http://www.chinacdc.cn/zxdt/200808/t20080802_31811.htm (accessed November 2016).

11 Fan Yongxiang, Peng Rong, Wang Zhutian. Analysis on status quo of China food standards. *Chinese Health Standard Management*, 2012, 3(9): 2–9.

12 Measures for the Administration of National Food Safety Standards http://www.gov.cn/flfg/2010-11/10/content_1742131.htm (accessed November 2016).

13 Ministry of Health promulgated 66 new national safety standards for dairy products such as Raw Milk, http://www.gov.cn/gzdt/2010-04/22/content_1589981.htm (accessed November 2016).

14 Circular of the Ministry of Health and the Ministry of Agriculture on Printing and Distributing the 2010 Work Program for Cleanup of National Food Safety Standard (Wei Ban Jian Du Fa [2010] No.106)

15 Launching the Clean-up Project on Food Packaging Materials by seven ministries, http://www.gov.cn/gzdt/2009-12/04/content_1480119.htm (accessed November 2016).

16 Wang Zhutian, Fan Yongxiang. Food safety standard system cleanup and improvement research. *Chinese Health Standard Management*, 2014, 5(10): 6–10.

17 Notification with regard to the Integration Project Plan of National Food Safety Standards by National Health and Family Planning Commission, http://www.nhfpc.gov.cn/sps/s3593/201405/535f5c0dc50b407f9da17593948e0444.shtml (accessed November 2016).

18 National and International Food Safety Standards Contrastive Analysis Project Report, internal document of China National Center for Food Safety Risk Assessment.

19 Food Safety Law of People's Republic of China (Presidential Order No. 21), http://www.gov.cn/zhengce/2015-04/25/content_2853643.htm (accessed November 2016).

20 China National Center for Food Safety Risk Assessment, www.cfsa.net.cn (accessed November 2016).

21 National Food Safety Standard database search platform, bz.cfsa.net.cn/db (accessed November 2016).

23

Lessons for China from US Food Safety History[1]

Fred Gale and Sandra Hoffmann

US Department of Agriculture, USA

23.1 Introduction

China's consumers face many hazards in their foods, including melamine in infant formula, toxic dyes in egg yolks, meat from diseased animals, cooking oil recycled from waste, and heavy metals in rice and vegetables. While these food safety problems seem shocking, similar problems were commonplace in Europe and the United States 100 years ago.

In 1913, monthly circulars distributed by the Chicago Department of Health [1] warned local residents that certain foods could cause disease or death. The pamphlets reported dozens of deaths in the city weekly from tuberculosis, diphtheria, diarrhea, and other diseases, many transmitted by food. The authors sternly cautioned Chicago residents to avoid street vendors selling cold drinks, "dirty ice cream," ice in beverages, and uncooked vegetables. Readers were warned that tuberculosis could be spread by merchants who polished fruit by breathing on it and shining it with a dirty handkerchief. The pamphlets advised readers to find out where their milk came from and warned mothers that children who drank cow's milk were less likely to survive the summer than those breast fed, and gave instructions for pasteurizing milk at home. Circulars reported fines assessed on unlicensed restaurants and unsanitary milk depots.

The United States and Europe have made significant progress over the past century in addressing food safety problems. Americans and Europeans are now shocked by similar problems in contemporary China. In this chapter we explore parallels between nineteenth-century food safety problems in the United States and Britain, and those experienced today in China. We also look at parallels in economic and institutional development and what lessons these parallels might provide for China as it works to improve food safety today.

---

[1] Note: The views expressed in this article are those of the authors and do not necessarily reflect the positions of the US Department of Agriculture or the Economic Research Service.

Food Safety in China: Science, Technology, Management and Regulation, First Edition.
Edited by Joseph J. Jen and Junshi Chen.

23.2 Food Safety Then and Now

Advances in disease control, toxicology, immunizations, testing, and sanitation have helped China to avoid many serious food-borne diseases, yet many of the problems and behaviors observed in nineteenth-century Europe and North America are commonplace in twenty-first-century China. This suggests that the problems are not wholly or even primarily technical, but rather are problems of management and institutional structure.

A number of food safety problems prevalent in nineteenth-century Britain and the United States are now common China (see Table 23.1). In nineteenth-century Britain and the United States, it was common practice to mix inferior materials into products like flour, beer, and tea; add dyes, flavorings, and whitening agents to hide inferior materials or spoilage; or to brush hams with borax, creosote, salt, and red dye to make them appear well-smoked [2]. During the 1860s, as much as one-fifth of beef supplied in Great Britain came from diseased animals [3]. The sale of meat from diseased swine was

Table 23.1 Similar food safety problems in three countries.

Britain	United States	China
Problem: Selling meat from diseased animals		
1863: As much as one-fifth of beef in London was from diseased animals. Traders used fat from healthy animals to hide problems of diseased carcasses [2]	1870s: Reports that US meatpackers processed the carcasses of swine that had died from hog cholera raised alarms [4]	2014: Police report breaking up a network that sold pork from diseased pigs in 11 provinces [39]
Problem: Nonfood ingredients used as substitutes to reduce cost		
1858: Lozenge makers replaced sugar with plaster of Paris or limestone to reduce costs; 20 people died when arsenic was used by mistake [6]	1900: According to a US Senator, "… investigation during the last session of Congress showed that very dangerous … substances were being used to adulterate flour [which] impaired the credit of American flour in foreign countries." [22]	2008: Flour was adulterated with talcum powder and laundry detergent [40] 2009: Pesticide, bleach, and detergent were added to flour used for steamed bread [41]
Problem: Infants harmed by adulteration of milk or infection with pathogens		
Late 1800s: Rising infant mortality was believed to be linked to the use of adulterated or infected milk [2]	1900: "Last month over four hundred babies … were killed by poisoned milk … contaminated by a … preservative liquid, known as formaldehyde. This toxic agent has been introduced into the dairy business under various fancy names." [42] 1906: An advocate of "pure food" attributed high death rates of infants in New York City to pathogens and chemical preservatives in milk [43]	2004: Children died from malnourishment after consuming infant formula containing flour and other non-nutritive substances [44] 2008: Children died of kidney failure after consuming milk adulterated with melamine [45]

Source: Compiled by authors from sources cited.

common in the United States during hog cholera epidemics in the early twentieth century [4]. Milk, alternately viewed as "the perfect food" and as a dangerous vector for the spread of disease, was a major concern [5].[2] High infant mortality rates in cities were believed to be linked to consumption of milk that was adulterated or was infected with bacteria. There were complaints about the poor quality of "swill" milk produced by poorly nourished cattle fed on grain mash from breweries, and it was common for milk sellers to dilute milk or add dyes or flavorings to milk that were sometimes harmful [2, 5].

Many of these examples are remarkably similar to those occurring in contemporary China. Similar adulterants are often added to foods. The appearance and taste can be altered by using bleach, dyes, chemicals, or animal fat. Preventing the butchering and sale of meat from diseased animals has been a major concern for Chinese authorities. Problems with milk are probably the most prominent current food safety concern in China. China's food safety challenges today include hazards from residues of toxic pesticides, antibiotics, and other chemicals that were not yet in use during the nineteenth century. China's most prominent milk-adulteration incident came to light in 2008 when the chemical melamine was found to have been added to mask the watering-down of milk by artificially increasing the apparent protein content.

23.3 Urbanization and Food Safety

In the US and Britain in the nineteenth century and in contemporary China, widespread food safety problems were preceded by a period of very rapid urbanization. Urbanization disrupts the social and market relationships that consumers had previously relied on to help assure food safety. In agrarian societies, people often produce food for their own consumption or they purchase food produced and sold locally. Repeated transactions among the same parties provide incentives to maintain food safety and quality. As societies urbanize, new mechanisms must be developed to assure safety in longer, more anonymous supply chains. For example, European society needed new guarantors of product standards to replace medieval trade guilds that declined as industrialization progressed [2]. Urbanization and industrialization increases the frequency of impersonal market transactions creating wider opportunities for fraud. In the United States, the development of a nationwide system of railways and refrigeration in the nineteenth century allowed regional specialization in agricultural production and nationwide transport of fresh meat, but also led to disease outbreaks and concerns about unsanitary meat [4].

The development of reliable mechanisms for assuring food safety and quality tends to lag behind changes in food supply chains associated with urbanization. In Europe and North America, public frustration with the inability to rely on the safety and quality of food led to pressure to create public institutions designed to assure food safety [6]. There is similar frustration in China today. In each of the three countries the first major national food safety legislation was introduced as the population became predominantly urban (see Figure 23.1). Britain introduced its first food adulteration law in 1860 as the urban share of its population approached 50%. The United States also introduced

---

[2] The concerns about milk are evident in 1913 Chicago Health Department bulletins [1].

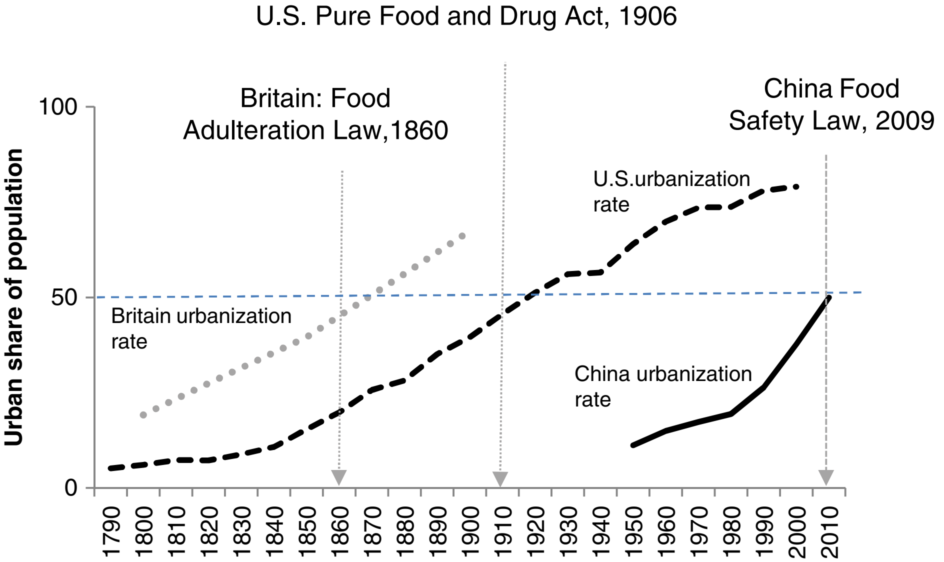


Figure 23.1 Urbanization rate and introduction of food safety laws. *Source*: Data compiled by authors. British population estimates from [46]; US estimates from [8] and www.census.gov; China data from www.stats.gov.cn.

its Pure Food and Drug Act in 1906 as its urbanization rate approached 50%. China introduced its first food safety law in 2009, just as its urbanization rate reached 50%. While urbanization data may not be strictly comparable across countries, the data illustrate the nexus between urbanization and food safety concerns. Recent rapid urbanization of China's population – from 30% in 1990 to 56% in 2015 – appears to be creating continued upheaval in its food system. The 2009 Chinese Food Safety Law was extensively revised in 2015 – only six years later. That same year President Xi Jinping and Premier Li Keqiang each identified food safety as a key government priority.

23.4 Development of US Food Safety Regulation

Historical similarities suggest that China might draw insights about food safety governance from experiences in developing modern food safety systems in Britain and the US. However, it may be dangerous to blindly adopt institutions and regulatory mechanisms from other countries without understanding how they developed. It is also important to understand the legal systems and cultural factors that influence the structure of rules in other countries. In the discussion that follows we look at the development of US food safety institutions and consider what lessons might be drawn from this experience for contemporary China.

In the United States, food safety regulation developed and evolved over many years in response to changes in the economy, science, and technology. The nineteenth century saw industrialization of the manufacturing sector, urbanization of the population, and mechanization and commercialization of the agricultural sector in the US [7]. Between 1860 and 1940, US Census Bureau data show that farmland area in the US more than doubled, from 407 million to over 1 billion acres, but the share of the population living on farms dropped by half, to 21%, as labor productivity increased [8].

The US food safety regulatory system developed in response to these fundamental changes in the economy. Problems began to arise as food and animals were traded over longer distances. Concerns included spread of animal disease, use of preservatives, adulteration with chemicals to hide spoilage, and unsanitary practices in processing plants. The regulatory structure continued to evolve in the twentieth century as new problems emerged and priorities changed.

The US Federal Government established a Bureau of Chemistry within the US Department of Agriculture (USDA) in 1862. Its initial focus was testing chemical fertilizer, but its later examination of chemical additives in foods was influential in the passage of the Pure Food and Drug Act of 1906 [12]. The USDA established a Bureau of Animal Industry in 1884 that had responsibilities for controlling animal disease and played an important role in meat inspection, the most visible food safety issue at the time. The US Meat Inspection Act was also enacted in 1906.

During the early twentieth century, food safety challenges continued and concern arose about conflicts of interest between the USDA's role in promoting agricultural production and its role in protecting consumers [9]. Under the Food, Drug, and Cosmetics Act of 1938 the USDA's Bureau of Chemistry was moved to the then-new "Federal Security Agency." It was renamed the Food and Drug Administration and in 1953 it was transferred to the Department of Health, Education, and Welfare, predecessor of the current Department of Health and Human Services.

During the decades that followed, laws were revised or amended to address major changes in the food supply, such as significant growth in the poultry industry in the 1950s, and development of new sweeteners, dyes, and pesticides following World War II. The Bureau of Animal Industry's veterinary and meat inspection functions were eventually split into two separate USDA agencies: the Animal and Plant Health Inspection Service (APHIS) and the Food Safety and Inspection Service (FSIS).

During the 1990s, meat again emerged as a focus of food safety attention. Contamination with bacteria could not be detected by sensory examination of animals and carcasses for lesions, other visible evidence of disease, and filth, as required by the 1906 Meat Inspection Act. The 1996 pathogen reduction rule reflected a shift toward prevention of contamination by adding a requirement that processors adopt standard operating procedures, identify "critical points" in the manufacturing process vulnerable

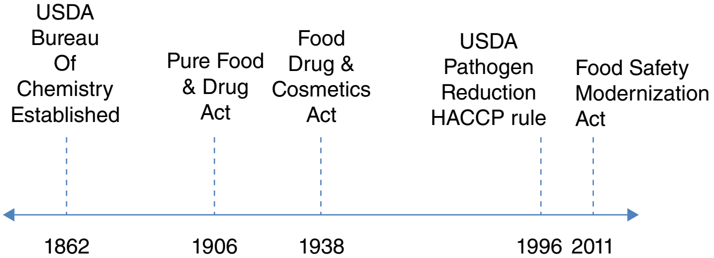


Figure 23.2 Highlights of US food safety regulatory history. *Source*: Compiled by authors from US Food and Drug Administration, "History," http://www.fda.gov/AboutFDA/WhatWeDo/History/default.htm (accessed June, 2015).

to contamination, specify and implement corrective actions, and maintain detailed records of these actions for inspectors' review [10].

The 2011 Food Safety Modernization Act (FSMA) continued the move toward prevention by requiring all food suppliers to adopt hazard analysis and control systems similar to those mandated by the 1996 rule for meat processors [11]. The Act uses a "farm to fork" approach to food safety that evaluates the entire supply chain, calls for regular inspections of facilities, and requires importers to ensure the safety of food procured from foreign suppliers.

23.5 Lessons from History

The long and complicated development of food safety regulation in the United States involved numerous laws, amendments, and institutional innovations to implement them. We offer a few lessons that can be drawn from the US experience.

23.5.1 An Informed Public Propels Food Safety Reforms

Public pressure for government action to address food safety problems was essential to early food safety reforms in both the United States and Britain. In both countries growing public awareness of food safety problems was elevated by scientific reports and news media. Incidents that gained public attention, like deaths due to toxic candy in Britain and reports of putrid meat supplied to US soldiers served as triggers for legislative action – much as public outrage over deaths from contaminated infant formula and news of widespread illegal feed additives spurred reform in China.

In both Britain and the United States, prominent scientists played a leading role by documenting food safety problems and their causes, and by advocating reforms. Frederick Accum in England in the 1850s, and Harvey Wiley in the United States from the 1880s through the 1900s were prominent scientists who used their epidemiological research on food adulteration and resulting disease to campaign for pure food legislation [6]. Daniel E. Salmon established cutting-edge bacteriological research at the US Department of Agriculture that served as a foundation for Federal animal disease control programs [4].

Scientific journals provided these scientists with vehicles to inform the public about the implications of their research findings for the public's health [6, 9]. The popular press played a role by translating this information for a wider public and promoting its broad dissemination. In the United States, a movement among reform-oriented journalists known as "muckrakers" exposed abusive business practices, in popular magazines such as *Collier's Weekly* and *Ladies Home Journal* [13]. Perhaps the most prominent and influential example of this literature was Upton.

Sinclair's novel *The Jungle* which described filth, chemical treatment of diseased meat, and other unsanitary and abusive practices in Chicago meat-packing plants [14]. These exposés of adulteration and unsanitary practices helped generate public pressure for food and drug reform [6, 9, 15]. Numerous historians highlight the role of civic organizations in the United States including the Women's Christian Temperance Union, the General Federation of Women's Clubs, and the National Consumers League, as well as farmers groups and business organizations in campaigning for both local and national food safety legislation [6, 9, 16].

Another popular book published in 1933, *100 000 000 Guinea Pigs* [17], warned US consumers that they were routinely ingesting toxic chemicals and pesticide residues in foods.[3] The same year, FDA officials prepared an exhibit of deceptively labeled foods that was known as “The American Chamber of Horrors” [19]. Both criticized weaknesses in the 1906 law and influenced enactment of the 1938 Food, Drug, and Cosmetics Act.

In both Britain and the United States, public outrage over highly publicized events triggered food safety reform. In Britain, mistaken adulteration of peppermint lozenges with arsenic killed 20 people (including 10 children) and sickened several hundred more in the city of Bradford during 1858. Public revulsion over these poisonings precipitated passage of the 1859 Bill to Regulate the Keeping and Sale of Poisons and the 1860 Adulteration Act [6]. In the United States, public concerns about meat were heightened by accusations that meat packers supplied “embalmed” beef (putrid meat masked by chemicals) to soldiers during the Spanish-American War [5]. Publication of The Jungle, while not a physical tragedy, influenced public opinion and played a role in President Theodore Roosevelt’s support for meat safety legislation [13]. The 1996 pathogen reduction rule was prompted in part by hundreds of illnesses and the deaths of four children linked to consumption of ground beef at outlets of a fast food chain [10, 18]. The 2011 Food Safety Modernization Act was influenced by another string of illnesses linked to spinach and by publicity about adulterated products imported from China. As in the early 1900s, political momentum needed to secure passage of the 2011 Act was built by newspapers and other media outlets that publicized food safety incidents as well as an effective alliance of consumer groups and business organizations.

Two important lessons can be drawn from this history. The first is the importance of having or developing the scientific capacity to provide reliable surveillance of the safety of the food supply. The second is the importance of transparency and informing the public about safety issues in the food supply. Openness in public information about the safety of the food supply is important to developing a constituency for stronger food safety programs. Moreover, as food safety programs become more effective and reliable, public information provides a means of building trust in the safety of the food supply.

Like nineteenth-century Britain and the United States, China has an emerging health-conscious class of educated consumers and an active news media that has disseminated information and generated public pressure for stronger regulation. However, the news media’s role in the reform process is limited by government control and reports that some media outlets have demanded payments from companies to withhold publication of negative articles. China also lacks the strong nongovernmental organizations that gave common citizens a means of advocating food legislation in the United States. In China, nongovernmental organizations – including a women’s federation, industry associations, and farmer cooperatives – are kept under tight control, and there are no prominent consumer groups.

China also lacks prominent scientists like Frederick Accum in Britain and Harvey Wiley in the United States, who played a key role as reformers [6]. China does not have a laboratory like Wiley’s Bureau of Chemistry in the United States or the Analytical

---

[3] While this book was influential, some critics described it as unscientific and some assertions later were shown to be false or exaggerated.

Sanitary Commission established in Britain by Thomas Wakley and Arthur Hill Hassall that publicized problematic food additives [20].

23.5.2 National Rules are Needed to Assure Food Safety in a National Market

An important lesson from the history of food safety law in the US is that the jurisdictional scope of food safety laws needs to correspond to the geographic scope of the market. In an agrarian society, food markets are local, and local standards and enforcement tend to prevail. As society urbanizes, markets become national in scope, requiring national rules.

In the early history of the United States, food safety was regulated solely by state law and local ordinance. In 1785, Massachusetts was the first state to enact a law against food adulteration, and many other state laws were enacted during the century that followed. By the late nineteenth century, the United States had a patchwork of differing laws, standards, and funding levels across states [9, 21].

The shortcomings of differing state laws became apparent as transportation improved, and food and animals began moving all over the country in a national market. In 1899, a senator from Illinois estimated that a quarter of states had passed pure food legislation within the previous three years [22]. The uneven regulatory structure across states prevented effective control of food safety, spread animal diseases, and created opportunity for fraud. Differences in state rules allowed undetected movement of diseased animals between states. Some states hid animal disease outbreaks or underestimated their effects on other regions as means of protecting farmers in their state [4].

As markets became more nationally integrated following the American Civil War, the lack of coordinated national rules led to more economic conflicts [23]. Enforcement was sometimes influenced by local industry interests and used as a form of local protectionism. On the other hand, large companies serving a nationwide market found that differing state laws were an obstacle to their expansion, and big companies became strong supporters of national food laws [6, 15, 23, 24].

In the United States, the national constitution impeded the enactment of national food safety laws. The United States is a federation of 50 state governments, and the constitution specifically gives the Federal government only a few regulatory powers – in particular the power to regulate trade between states – all powers not specifically granted to the Federal government by the constitution are reserved to the state governments.[4] For much of the nineteenth century, national laws regulating food processing could not be enacted because the US Supreme Court interpreted regulation of manufacturing industry as a state power.

Beginning in the 1880s, the Supreme Court began to broaden its interpretation of the scope of the Federal government's power to regulate interstate commerce [4, 6]. In a 1905 ruling (*Swift v. United States*), the US Supreme Court reasoned that the interstate commerce clause of the US constitution gave the US Congress the power to regulate meat packers because the packers affected the flow of commerce in meat between states, even though their activities were "local."

---

[4] This differs from Canada which is a federation of provinces, but the Federal government, rather than provincial governments, has residual power.

Today, US food safety law is a combination of federal, state, and local law. Federal law regulates the safety of any food shipped across state lines. State law governs the safety of food produced and sold exclusively within a state's boundaries, and sanitation and hygiene in restaurants and retail stores. State inspectors enforce state meat and food processing law. In many states, local governments may adopt retail and restaurant sanitation standards that are stricter than state standards and in all states, local governments adopt rules on how they will enforce sanitation standards in restaurants and grocery stores in their jurisdictions [25].

Consistency across states and localities occurs because state and local governments tend to look to national model codes or to federal rules in drafting their own rules. State governments typically draw on FDA model "food code" designed to assure adequate sanitation and hygiene in retail stores and restaurants. States often look to federal rules in drafting legislation governing meat processing and other food manufacture for products produced and sold within state boundaries. Yet in some cases, there is noticeable variation across states and localities. Recently variation has emerged in state laws governing GMO labeling and the regulation of unpasteurized milk produced and sold within the state.

China does not face the same legal constraints as the United States, but it is also struggling to move from a patchwork of provincial and city standards and regulations to a unified, national system. The transition is slowed by an approach to governance that gives local authorities a high degree of autonomy to implement laws, a long tradition of localized food markets, and inertia from local self-sufficiency policies carried over from the centrally planned economy. Even when national laws and standards are enacted, provinces still vary in the degree of local funding and enforcement.

As in the nineteenth-century United States, China's patchwork of local rules has become an impediment to companies serving a national market and to food safety enforcement. Some commentators accuse local officials of using food safety standards and testing methods to protect local companies from outside competitors [26, 27]. In past years, uneven funding levels led to lax implementation of animal inspections and veterinary rules by many local authorities. Over the last ten years, the central government began giving grants to fund disease control and other tasks in major hog-producing counties and subsidies to pay salaries at local veterinary stations to address the local funding shortfalls. In 2014, the central government began a pilot program to fund upgrades of food-testing capacity for county-level food-testing labs.

23.5.3 Food Safety Measures must be Practical to Ensure they can be Enforced

The risk reduction achieved from proposed food safety measures must be weighed against the practicality of implementing them and their restrictive impact on food supplies.

During the early 1900s, there was disagreement in the United States about the best way to prevent the spread of disease by milk: by pasteurizing milk or by certifying the sanitation of farms and suppliers [5, 28]. Advocates of "pure food" wanted to establish commissions of physicians that would oversee certifications of dairy farms, collectors and handlers of milk to certify that they maintained a pure water supply, a clean farm, and employed good hygiene and feeding of cows. However, certification doubled the cost of milk and only a negligible portion of the milk supply was ever certified.

Pasteurization was cheaper and did not require the extensive efforts needed to verify compliance with certification. Advocates of certification criticized pasteurization as a measure that could cover up unsanitary practices. Nevertheless, the process was adopted because it was cheaper and assured safe milk supplies for all consumers.

A German law introduced in 1900, dealt with the high proportion of cattle failing strict inspections by establishing a two-tier market with designated outlets for meat from these animals. Meat that passed inspection could be sold anywhere. Special shops were established to sell meat from diseased cattle and buyers were notified of the dangers, but this meat could not be supplied to hotels or restaurants [4].

The supply of qualified enforcement personnel limits the implementation of food safety measures. In the early twentieth century, British butchers claimed that health department meat inspections were inaccurate because the inspectors had little knowledge of livestock or meat, but officials refused to acknowledge the problem [3]. Diseased animals and meat moved to localities where inspections were lax [4].

China has adopted some of the world's strictest food safety standards and certifications that in many instances cannot be realistically implemented. For example, an author of this chapter once visited a model hog-raising village where farmers purportedly used "good agricultural practices" (GAP), a certification common in developed countries. A farmer interviewed there had a GAP schedule of activities posted on the wall that specified animal care and sanitation measures to be conducted throughout the day. The farmer mentioned that he liked raising pigs because he only had to spend a couple of hours per day tending them, suggesting that he did not adhere to the strict schedule required by GAP standards.

China has strict standards for testing a range of farm produce, feeds, livestock, and agricultural inputs for numerous adulterants, illegal additives, chemical residues, and chemical composition, but many laboratories do not have the capacity to conduct such extensive testing effectively on a large scale. A government evaluation report from a county in Hubei Province revealed that testing labs at the county level had few personnel with college degrees or other appropriate qualifications, that labs failed to carry out most of the testing protocols, much equipment was left idle, and labs selectively implemented directives from higher authorities [29].

If strict standards are rigidly enforced, it will restrict the supply of food to consumers. More often, strict standards are unevenly enforced, which is likely to undermine consumer confidence in regulation. A less stringent standard that can realistically be implemented and enforced may be more beneficial for consumers than a strict standard that is routinely violated.

23.5.4 International Trade Considerations Can Drive Positive Domestic Change

The international reputation of a country's food can motivate industry and government leaders to make necessary reforms and innovations to improve food safety. During the 1880s, Germany, Britain, Italy, and other European countries banned US pork and beef due to concerns about infection with trichinosis and other diseases. Controversy over meat caused diplomatic conflicts, but the prospect of losing export markets spurred the US industry to embrace measures to control animal diseases and to initiate inspection programs for meat. A senator praised an early food adulteration law for raising the international reputation of US flour and other products [22]. More recently, a USDA survey found that meat-packing plants with foreign ownership made greater investments in food safety measures than those focused on the domestic market [30]. Concerns about the safety of imported food were an important influence on the 2011 Food Safety Modernization Act [11].

International trade plays an important role in improving food safety in China. "Green food," China's first food safety certification, was introduced in the early 1990s to increase confidence in the country's exported food products. Other food safety certifications like HACCP, ISO-9001, and GAP were first introduced for export-oriented food producers and have since become more common for those serving the domestic market [31, 32]. China's inspection and quarantine authorities assisted farmers and processors of exported apple juice concentrate in adopting food safety practices [33]. Multinational retail chains operating in China have been leaders in introducing more stringent food safety systems to the domestic market [34]. Many of the standards and certifications initially adopted exclusively by exporters later came into widespread use in the domestic market as Chinese consumers became more willing to pay for food safety attributes [35, 36]. In the years following China's melamine-adulteration scandal, competition from imported infant formula brands has pressured Chinese dairy companies to upgrade their own food safety controls.

23.5.5 Food Safety Regulation Requires Coordination Across Government

Food safety regulation is challenging because it covers so many sectors – farm production, inputs, environment, transportation, markets, processing, retail, and food service, each of which can be regulated by a different agency. In the US, 15 federal agencies share responsibility for food safety, though most regulation is conducted by three: the US Food and Drug Administration, the US Department of Agriculture, and the US Environmental Protection Agency. Food safety can also be regulated at different levels of government. As discussed above, food safety in the United States is governed by local, state, and Federal law. Without attention and commitment, dividing responsibilities across multiple government agencies can lead to gaps in coverage and coordination problems.

The problems of dividing responsibilities and coordination are management issues that need deliberate focus. The new US Food Safety Modernization Act has explicit provisions intended to strengthen coordination between state and Federal food safety authorities. Within the US Federal government, different government agencies sign cooperative agreements that formalize coordination. Committees and working groups with members from different agencies and departments also help prevent duplication and gaps. There have been many proposals to improve coordination by consolidating food safety work in a single Federal agency, as was proposed earlier this year by President Obama [37].

These experiences show that no matter how governance of food safety is structured, there will be areas of interaction among different government authorities that will benefit from thoughtful coordination.

23.6 Concluding Remarks

China today benefits from more than a century of improvements in scientific knowledge, methods, and equipment. Just as important are advances in total quality management, risk assessment, risk analysis, and "farm to fork" approaches to food safety that emphasize preventive measures. Nevertheless, China still faces difficult food safety challenges.

While China is encountering many of the same problems with tainted meat, preservatives, dyes, and adulterations that were common in the nineteenth century, it also faces contamination with chemical residues, pharmaceuticals, and heavy metals that became widespread problems during the twentieth century. Moreover, China faces challenges in controlling food-borne pathogens like *E. coli* that have received less attention in China than adulterations and residue problems.

US food safety regulation and enforcement mechanisms have been refined and improved over the last two centuries. Yet food safety remains a public concern as new problems and vulnerabilities emerge. China's food safety professionals will also need to continually assess risks and make improvements.

Training skilled personnel with technical skills who are knowledgeable about the food industry are critical to the development of an effective food safety system. While China can import equipment and management systems, it takes time to develop a cadre of personnel to take charge of food safety functions in regulatory organizations and companies.

There is cause for optimism as a new generation learns about practices in other countries and takes the initiative to improve food safety. Recently, a grassroots NGO staffed by volunteers established a research center that compiled and published the first detailed study of food safety incidents to inform consumers about food safety incidents [38]. The founder – an MBA student from Tsinghua University –said she was inspired by the example of Harvey Wiley, the USDA scientist who was instrumental in pushing forward the first national food safety law in the United States.

Chinese citizens studying the history of food safety in other countries can find inspiration, as well as cautionary lessons. The authors hope that this chapter will spur more study on this topic.

References

1 Chicago School of Sanitary Instruction. 1921. *Chicago's Health* XV.

2 E.J.T. Collins. 1993. Food adulteration and food safety in Britain in the 19th and early 20th centuries. *Food Policy* 18(2): 95–109.

3 P.J. Atkins. 2004. The Glasgow case: meat, disease and regulation, 1889–1924, *The Agricultural History Review* 52(2): 161–182.

4 A.L. Olmstead and P.W. Rhode. 2015. *Arresting Contagion: Science, Policy, and Conflicts Over Animal Disease Control*. Cambridge: Harvard University Press.

5 H. Levenstein. 2012. *Fear of Food*. Chicago: University of Chicago Press.

6 J. London. 2014. Tragedy, transformation, and triumph: Comparing the factors and forces that led to the adoption of the 1860 Adulteration Act in England and the 1906 Pure Food and Drug Act in the United States, *The Food and Drug Law Journal* 69: 315–342.

7 D.R. Hurt. (2002). *American Agriculture: A Brief History*. Purdue University Press.

8 A.L. Olmstead and P.W. Rhode. 2006. Farms – number, population, land, and value of property: 1850–1997 [Census years]. Table Da14-27 in *Historical Statistics of the United States, Earliest Times to the Present: Millennial Edition*, edited by S.B. Carter, S.S. Gartner, M.R. Haines, A.L. Olmstead, R. Sutch, and G. Wright. New York: Cambridge University Press. http://hsus.cambridge.org/HSUSWeb

9 M.T. Law. 2006. How do regulators regulate? Enforcement of the Pure Food and Drugs Act, 1907–38, *Journal of Law, Economics and Organization* 22(2): 459–489.

10 US Department of Agriculture, Food Safety and Inspection Service. 25 July 1996. Pathogen reduction, Hazard Analysis and Critical Control Point (HACCP) systems; final rule, *Federal Register* 61(144): 38805–38989. http://www.fsis.usda.gov/OPPDE/rdad/FRPubs/93-016F.pdf (accessed June, 2015).

11 S. Hoffmann. 2011. U.S. food safety policy enters a new era, *Amber Waves*, 9(4): 24–29. http://www.ers.usda.gov/amber-waves/2011-december/us-food-safety-policy.aspx#.VY59IF_D-5s (accessed June, 2015).

12 M.T. Law and G.D. Libecap. 2006. The determinants of progressive era reform: The Pure Food and Drugs Act of 1906, in *Corruption and Reform: Lessons from America's Economic History*, edited by E.L. Glaeser and C. Goldin. Chicago: University of Chicago Press.

13 A.F. Kantor. 1976. Upton Sinclair and the Pure Food and Drugs Act of 1906, *American Journal of Public Health* 66(12): 1202–1205.

14 U. Sinclair. 1906. *The Jungle*, republished online at https://www.gutenberg.org/files/140/140-h/140-h.htm (accessed June, 2015).

15 I.D. Barkan. 1985. Industry invites regulation: The passage of the Pure Food and Drug Act of 1906, *American Journal of Public Health* 75(1): 18–26.

16 J. Haydu. 2012. Frame brokerage in the Pure Food Movement, 1879–1906, *Social Movements Studies*, 11(1): 97–112.

17 A. Kallet and F. J. Schlink. 1932. *100,000,000 Guinea Pigs: Dangers in Everyday Foods, Drugs, and Cosmetics*, New York: The Vanguard Press.

18 M. Nestle. 2010. *Safe Food: The Politics of Food Safety*. Berkeley, CA: University of California Press.

19 R. D. Lamb. 1936. *American Chamber of Horrors*, New York: Farrar & Rinehart.

20 B. Charnley. 2008. Arguing over adulteration: the success of the Analytical Sanitary Commission, *Endeavour*, 32(4): 129–133.

21 R.T. Law. 2003. The origins of state pure food regulation, *The Journal of Economic History*, 63(4): 459–489.

22 W.E. Mason. 1900. Food adulterations, *The North American Review*. 170(521): 548–552. http://www.unz.org/Pub/NorthAmericanRev/?Period=1900_04 (accessed June, 2015).

23 G.D. Libecap. 1992. The rise of the Chicago Packers and the origins of meat inspection and antitrust, *Economic Inquiry* 30: 242–262.

24 D.J. Wood. 1985. The strategic use of public policy: Business support for the 1906 Food and Drug Act, *The Business History Review* 59(3): 403–432.

25 C.A. Roberts. 2001. *The Food Safety Information Handbook*. Westport, CT: Onyx Press.

26 Xianjun Li. 2007. Zhiliang Jiance Yao Dapo Difang Baohu Zhuyi (Quality testing must break local protectionism), *Xinhua News*, February 16. http://news.xinhuanet.com/comments/2007-02/16/content_5743825.htm (accessed May, 2015).

27 *Zhengzhou Evening News*. 2015. Zhua Shipin Anquan Dapo Difang Baohu Zhuyi (Local protectionism must be broken to achieve food safety), *Zhengzhou Evening News*, March 9, page A08. http://zzwb.zynews.com/html/2015-03/09/content_641716.htm (accessed May, 2015).

28 D. Block. 1999. Purity, economy and social welfare in the progressive era pure milk movement, *Journal for the Study of Food and Society* 3(1): 20–27.

29 Baokang County Oversight Office. 2015. Xian ji Jianyan Jiance Jigou Zhenghe de Nandian yu Duice (Conformity of County-Level Inspection and Testing Organizations: Difficulties and Countermeasures), investigation report, Xiangyang City (Hubei Province) Oversight Office, April 27. http://www.hbxysbb.gov.cn/dcyj/201504/t20150427_29999.html (accessed May, 2015).

30 E. Golan, T. Roberts, E. Salay, J. Caswell, M. Ollinger, and D. Moore. 2004. *Food Safety Innovation in the United States: Evidence from the Meat Industry*, US Department of Agriculture, AER831. http://www.ers.usda.gov/publications/aer-agricultural-economic-report/aer831.aspx (accessed May, 2015).

31 L. Calvin, F. Gale, D. Hu, and B. Lohmar. 2006. Food safety improvements underway in China, *Amber Waves*, November. http://www.ers.usda.gov/amber-waves/2006/november/food-safety-improvements-underway-in-china/ (accessed November 2016).

32 Z. Wang, H. Yuan, and F. Gale. 2009. Costs of adopting a Hazard Analysis Critical Control Point System: Case study of a Chinese poultry processing firm, *Review of Agricultural Economics* 31(3), 574–588.

33 F. Gale, S. Huang, and Y. Gu. 2010. *Investment in Processing Industry Turns Chinese Apples into Juice Exports*, US Department of Agriculture, FTS-344-01. http://www.ers.usda.gov/media/141094/fts34401_1_.pdf (accessed June, 2015).

34 H.F. Gale and D. Hu. 2012. Food safety pressures push integration in China's agricultural sector, *American Journal of Agricultural Economics* 94(2): 483–488.

35 C. Zhang, J. Bai, and T.I. Wahl. 2012. Consumers' willingness to pay for traceable pork, milk, and cooking oil in Nanjing, *Food Control* 27: 21–28.

36 Z. Wang, Y. Mao, and F. Gale. 2008. Chinese consumer demand for food safety attributes in milk products, *Food Policy* 33: 27–36.

37 C. Doering. Obama proposes single agency to oversee U.S. food safety, *USA Today*, 2 Feb 2015. http://www.usatoday.com/story/news/2015/02/02/obama-proposes-consolidating-food-safety-oversight/22764529/ (accessed November 2016).

38 J. Ma. 2015. Going Public, *NewsChina*, June 2015. http://www.newschinamag.com/magazine/going-public (accessed May, 2015).

39 Legal Evening News. 2015. Qian Yu Dun Bing Si Zhurou Liuru 11 Shengqu (over 1000 tons of diseased pork marketed in 11 provinces). January 12. http://business.sohu.com/20150112/n407723835.shtml (accessed November 2016).

40 *Boxun*. 2008. Shandong Heixin Mianfen Hunru Huashifen, Zhiqingzhe Cong Bu Mai (Sinister Shandong flour contains talcum powder, knowledgeable people never buy it), October 20. http://www.boxun.com/news/gb/china/2008/10/200810201247.shtml (accessed June, 2015).

41 *China Daily*. 2009. Mantou Jubaodi Nongyao yi Zengjia Kougan (Pesticide reportedly added to Shaanxi Steamed Bread to Increase Flavor), March 13. http://news.sina.com/oth/chinesedaily/301-101-101-107/2009-03-13/05193708235.html (accessed November 2016).

42 *The Cincinnati Lancet-Clinic*. 1900. Formaldehyde poisoned milk. 45 (August 25): 193–194.

43 *Chicago Tribune*. 1906. Milk killing N.Y. babes: Expert warns of danger from dairymen's dishonesty, 24 December, p. 10.

44 State Council Emergency Management Office. 2005. Anhui Fuyang Liezhi Naifen Shijian (Fuyang Inferior Milk Powder Incident), August 9, http://www.gov.cn/yjgl/2005-08/09/content_21396.htm (accessed November 2016)

45 *China Youth Daily*. 2009. Sanlu Sanjuqingan Naifen Shijian Quanguocheng Huifang (Review of the San Lu Melamine Milk Powder Incident), January 1. http://news.sohu.com/20090101/n261527309.shtml (accessed June, 2015).

46 P. Bairoch and G. Goertz. 1986. Factors of urbanisation in the nineteenth century developed countries: A descriptive and econometric analysis, *Urban Studies* 23: 285–305.

24

Food Safety Regulatory Inspection in China

Zhenhua Gu[1], Congqian Qiu[1] and Zhinong Yan[2]

[1] *Shanghai Food and Drug Administration, China*
[2] *Ecolab (China) Investment Co., China*

24.1 Overview of Food Safety Regulatory Inspection

24.1.1 The Definition of Food Safety Regulatory Inspection

Food safety regulatory inspection refers to the process that government authorities implement for the administrative regulation of food production and business activities, for food producers to comply with food safety law and regulation, and to enable legal action to be taken in the case of failure of compliance with the statutes and regulations [1]. It is equally enforceable, standardized, authorial, technical, and regulated. Management of food safety is defined by the FAO/WHO, within the guideline for strengthening food safety management systems to ensure food quality and safety, as an obligatory regulation activity to enable national or local government authorities to ensure all foods are safe, healthy and suitable for human consumption during production, processing, storage, transportation and trading, and for honest and accurate labeling to protect consumer health [2]. The most important task of food safety management is to reinforce food statutes to ensure food safety by preventing the production and selling of non-wholesome, counterfeit and fraud foods.

24.1.2 The Importance of Food Safety Regulatory Inspection

Food safety is essential to people's lives, and is also a significant economic and political issue. The objective of food safety regulatory inspection is to ensure food safety and protect public health and lives. It will improve the food industry's healthy development, maintain the market order, protect civilian's legal rights and crack down on criminal actions in making adulterated foods. The failure of food safety regulatory inspection will lead directly to uncontrollable food safety issues, disorder in the food market and even nationwide social crisis, which will significantly influence the capability and credibility of the government.

Food Safety in China: Science, Technology, Management and Regulation, First Edition.
Edited by Joseph J. Jen and Junshi Chen.

24.1.3 Basic Principles and Tasks of Food Safety Regulatory Inspection

24.1.3.1 Primary Principles

The newly revised China Food Safety Law promulgated in 2015 is based on four principles of food safety regulatory inspection, which include preventive control, risk management, whole process control and shared responsibility [3].

"Preventive control" is to integrate all effective approaches to prevent potential risk factors from occurring during food production, manufacturing, transportation, storage and trading. It is to control and reduce the food safety hazards prior to causing any damage to people's health, to prevent it from the very beginning.

"Risk management" refers to applying the basic principles of risk analysis and conduct science-based risk surveillance and evaluation to determine food safety regulatory inspection focuses, approaches and frequency; manage food safety risks based on the severity rate; manipulate food safety problems using scientifically evaluated control technologies; gain the maximum output to protect public health.

"Whole process control" can be understood from two types of processes. Firstly, it means management of the whole food chain from farm to table, including the production of primary agricultural products, harvesting and slaughtering, food processing, packaging, transportation, distribution, retailing and consumption. It also includes the food ingredients, additives, packaging materials, food grade detergents and sanitizers, food processing equipment and facilities, and also monitoring the food manufacturing and serving environment. The new China Food Safety Law promulgated in 2015 clearly states that the government shall establish a traceability system for the whole food chain. The food industry shall develop a traceability program so that the whole food chain is connected and can be traced if any food safety incident occurs. Secondly, it refers to the process of food manufacturing, retailing and serving, adopting good manufacturing practice (GMP), good hygiene practice (GHP), sanitation standard operating procedures (SSOPs) and hazard analysis and critical control points (HACCP).

"Shared responsibility" is to utilize all the resources, including government regulation, different agencies, food manufacturers, trading and serving industry associations, consumer groups, media and each individual, to pay attention to, to participate in and support food safety. These responsibilities should include government regulation, primary accountability from the food industry, self-discipline and communication within trade associations, self-protection and influence from consumers, monitoring from media and the involvement of insurance. The ideal situation is to have all shareholders involved in food safety management.

24.1.3.2 Enforcement

The enforcement of food safety includes operation permits, administrative inspection, randomized sampling and monitoring, food safety incident investigation and administrative punishment by food safety regulation agencies.

1) *Operation license and permit*: The government authority issues a license for food manufacturing, trading and catering services with sufficient qualifications, and a permit and registration for new food ingredients, additives, health foods, new packaging materials and other food-related products.
2) *Administration inspection*: The food safety authority conducts inspections of food manufacturing, trading and catering for compliance with regulations, standards and technical practices.

3) *Randomized inspection*: The food safety authority conducts randomized inspections through sampling and testing of food ingredients, products, food additives, packaging materials, cleaning and sanitation chemicals, equipment, plant and its environment.
4) *Food safety incidence investigation*: The food safety authority investigates causes, intentions, consequences of actual or potential health risks from microbial and other contamination, primary responsibilities and actions to reduce the risks of the incidents.
5) *Administrative penalties*: The food safety authority issues administrative penalties for violating food safety law, standards and rules. The penalties cover warnings, confiscating illegal income, food products, tools, equipment and ingredients, fining, forcing production to stop and suspending licenses.

The food safety authority has the power to conduct the following activities:

a) Enter facilities and perform onsite inspections;
b) Take samples and conduct testing of food products, additives and food-related products;
c) Review and copy contracts, invoices, records and other documents;
d) Close down production, detain food products, additives and other food-related products which do not comply with food safety standards or pose food safety risks with convincing evidence; and
e) Close down the facility where the violation is found.

24.2 The History of Chinese Food Safety Regulatory Inspection

24.2.1 The Development of Food Safety Regulatory Inspection

Food safety regulatory inspection is an important part of the Chinese national regulations. It has been revised based on policies, economics and cultural changes. Its development commenced in 1949 when the new China was founded. It has experienced several significant periods, including technical management without government authority (disease prevention and quarantine), administrative regulation (department of health), multiple government agency regulation and single government agency regulation [4–6].

24.2.1.1 Technical Supportive Management (Disease Prevention and Quarantine)

On 26 January 1953, during the 167th meeting, the China State Administration Council determined to establish disease prevention and quarantine stations under the direction of the Department of Health above county level, to be in charge of food wholesomeness and hygiene inspections. In the 206th meeting of the China State Administration Council in 1954, it was decided to start a national hygiene inspection system, giving authority to the Department of Disease Prevention and Quarantine to manage food hygiene. In August 1965, the State Council sent an official note to relevant agencies regarding the "Trial Regulations for Food Hygiene" developed by five ministries, including health and commerce [7]. This was the first food hygiene regulations in China.

In August 1979, the State Council revised and promulgated the "China Food Hygiene Regulations" [8], and the Disease Prevention and Quarantine Agency developed the legal basis for food hygiene regulation. In 1982, the National People's Congress Standing Committee issued the "China Food Hygiene Law (trial)" [9], which was the first food safety law. It assigned the Ministry of Health to be in charge of national food hygiene, and created the Institute of Food Hygiene Inspection and Testing under the Disease Prevention and Quarantine Agency to carry out food hygiene inspections.

24.2.1.2 Administrative Regulation (Health Agency)

In 1995, the National People's Congress Standing Committee promulgated the revised "China Food Hygiene Law", giving the Health Agency (Department of Health) the authority and primary role to execute the enforcement of the law, and began the national food hygiene inspection system, in which the Department of Health above county level conducted the food hygiene role, replacing the Institute of Hygiene Inspection and Testing [10].

24.2.1.3 Regulation by Multiple Ministries (Multiple Agency System)

In September 2004, the State Council issued a notice on "The decision on continuous improvement in food safety," in which it was clearly requested that each agency cover one section of the food production chain, with rather than regulation through commodities [11]. The Ministry of Agriculture was responsible for primary agri-products, the Quality and Inspection Agency for inspection of food processing and import/export, the commerce agencies for food transportation and trading, the food ministries for catering, and the Food and Drug Administration agencies on the overall inspection, coordination and investigation of the most important food safety incidents.

In 2009, the National People's Congress Standing Committee revised and issued the "China Food Safety Law," in which food safety was first used to replace the food hygiene and regulation system, and a "combination of partial regulation of commodities, and integrated and specific regulation" was ensured by law [12]. A Food Safety Committee was established within the State Council with an office that carried out the integrated coordination of food safety. The health agencies were responsible for food safety risk surveillance and assessment, food safety standards, overall management, major food safety crisis investigation and publishing major food safety information. The Food and Drug Administration was responsible for catering regulation and healthy foods. In 2010, the State Council reallocated the duties of overall regulation, investigation of major food incidents and publishing food safety information to the Food Safety Office [13]. Local government also set up Food Safety Committee Offices and conducted the tasks accordingly.

24.2.1.4 A Single Agency System (CFDA)

In 2013, following the decision by central government to broaden and deepen reform, the China Food and Drug Administration (CFDA) was formed to embrace the function of quality inspection (CIQ) and commerce, to include food production, trading and catering in its remit. The Food Safety Committee Office is located in the CFDA (Figure 24.1; 14). Thus a "single" agency regulation system was initiated comprising the CFDA (food production, trading and catering, and overall coordination, investigation of major food safety issues, and publishing food safety data); the Ministry of Agriculture

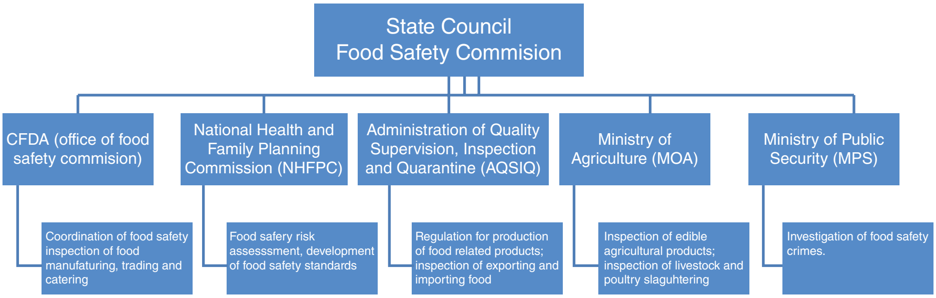


Figure 24.1 China Food Safety governance structure.

(primary agri-products), the CIQ (importing and exporting foods) and the Ministry of Health (food safety risk surveillance, assessment and standards).

24.2.2 The Dynamics of Food Safety Regulation Mechanisms

24.2.2.1 The Regulatory System of Food Hygiene Focusing on Prevention of Food Poisoning

Prior to the reforming and opening up policy of the 1980s, economic development was slow under the planning system. The quantity of food was not enough, food production capacity was far behind and clothing was not sufficient to meet people's needs. Input in food regulation was not enough to carry out the regulatory work; laws and standards were not in place and had not even been developed yet. Food hygiene inspection had to be focused on prevention of food poisoning mainly caused by bacteria. Regulation targeted commodities such as grain, vegetable, fruits, dairy, meat and egg.

24.2.2.2 The Regulatory System Coexisting between Food Poisoning and Contamination Prevention

Since 1978, when the policy of opening up was introduced, food production and commercialization have been growing rapidly. The quantity of food supply increased, giving enough food to people. The food industry became an important way for people to earn a living. However, a negative result of the rapid economic growth was environmental deterioration and crop contamination due to heavily contaminated water and soils. Food became spoiled because of poor transportation, storage and sales conditions. The illegal addition of non-food substances and the over-use of food additives led to intentional food safety incidents. These were major issues for food regulation and inspection. Meanwhile, prevention of food contamination from farm to table along the food chain, increasing awareness of food safety for food manufacturing and consumption, assuring food safety for big events like the Olympic Games and prevention of terrorism through food also drew attention and required immediate and clear regulation and management for the purposes of public security.

24.2.2.3 Food Regulatory Systems Focusing on Risk-Based Prevention and Management

In 2009, the first China Food Safety Law was developed and implemented after the melamine food scandal. The law required food safety risk surveillance and assessment systems to be established. This initiated risk-based food safety prevention and management systems in terms of legislation. Food safety risk surveillance was able to be conducted by assigned nationwide government bodies. Thereafter, legislation, standards development, regulation systems and plans for food safety have all been based on risk assessment.

This risk-based system was further emphasized in the newly revised China Food Safety Law in 2015. It requires food regulatory government bodies to determine the focus, methodology, frequency and risk ranking based on the holistic analysis of risk assessment, surveillance data and overall food safety status. The public should be alerted to consumption of high-risk food.

24.2.3 The Outcome and Results of Food Safety Regulations

In the past ten years, the Chinese government has continuously improved the regulation systems, developed innovative regulation mechanisms, established a structure for developing food safety standards and cracked down intentional food safety issues. The overall food safety status has improved steadily and it proceeds in an appropriate direction.

24.2.3.1 Continuous Improvement of Food Safety Legal Systems

Over the last decade, China has established food safety legal systems comprising the “China Food Safety Law” as the fundamental and core law, with supplementary regulations from administration, ministry and local levels. The “China Food Safety Law” issued in 2015 was significantly and historically revised from its predecessor, six years before, with 70% major revisions and 48% items added. It is considered to be the toughest law covering the whole food production chain. It was based on the principles of preventive control, risk management, whole-process control and social and shared responsibilities. It clearly states the roles of government, industry, associations and consumers in protecting food safety, establishes the requirement for risk surveillance and assessment and reinforces the consequences of violating the law.

24.2.3.2 The Increasing Trend in the Pass Rate of Products by Randomized Testing

The average pass rate for products tested by randomized sampling from markets has increased from 87.49% in 2005 [15] to 94.6% in 2010 [16], with a peak of 95.4% in 2014. Among the commodities, grain and its products, plant-originating oil, meat and processed meat, egg and egg products, and dairy products have reached a 97.6% pass rate; a 99.95% rate has been achieved for export products.

24.2.3.3 The Decreasing Trend for Food Poisoning

In 2005, there were 256 food poisoning incidents reported to the Ministry of Health nationwide, causing 9021 cases and 235 deaths [17]. Among these, 18 resulted in over 100 people being poisoning. In 2014, 160 incidents were reported with 5657 cases and 110 deaths. Among these, 74 incidents, with 842 poisoning cases and 110 deaths were considered as big events, and the remaining 86 incidences caused 4815 poisonings and no deaths [18]. These figures are listed in Table 24.1.

Table 24.1 Occurrence of nationwide food poisonings in 2005–2014.

Year	Incidences	People poisoned	Deaths
2005	256	9021	235
2006	596	18063	196
2007	506	13280	258
2008	431	13095	154
2009	271	11007	181
2010	220	7383	184
2011	189	8324	137
2012	174	6685	146
2013	152	5559	109
2014	160	5657	110

24.2.3.4 Significant Results of Specific Food Safety Campaigns

Routine inspections and enforcement have increasingly and systemically been strengthened across regions and regulatory government branches to focus on various points and difficult issues during food manufacturing and commercial operating. A series of activities were carried out against intentional adding or over-use of food additives, clenobuterol hydrochloride in lean meat powder, gutter oil, sick and dead swine, dairy products, oil, meat, Chinese liquor and functional foods. Some typical violation cases were inspected and prosecuted; those who conducted illegal operations were punished. In 2010, the Supreme Court, the Supreme Prosecutor, the Ministry of Public Security and the Ministry of Justice issued a notice to crackdown on criminal activities endangering food safety. It clearly stated the procedures and requirements for filing, investigating, suing and trial of suspected food safety cases. In 2011, the revised China Criminal Law (8th edition) [19] included a new rule for the conviction of food safety criminals, with punishments even including the death sentence. In 2014, a specific bureau was set up in the Ministry of Public Security to conduct criminal investigation of food safety. Provincial public security bureaus formed task forces for the investigation of food and drug criminal wrongdoings. In 2014, 26 000 crimes were investigated, with 1000 cases being transferred to the justice authority.

24.2.4 Investigation and Prosecution of Major Food Safety Incidents

24.2.4.1 Counterfeit Baby Formula in 2004 [20]

In April 2004, several cases of “big head disease” babies were found in Fuyang, Anhui province. The investigation indicated that the sick and dead babies were fed with fake powdered milk produced locally, to which starch and sucrose were intentionally added, resulting in malnutrition of babies due to less protein, fat and trace elements. The data showed that 189 babies had suffered from slight and moderate malnourishment, 28 from severe malnutrition, and there were 12 deaths.

Further investigation was undertaken and 49 fake baby formula manufacturers, one underground producer and three non-qualified companies were found; among these, 12 were local manufacturers.

A total of 21 violations involving 35 people resulted in criminal charges; 97 local officials were prosecuted as administrative punishment by the supervisory department.

24.2.4.2 Sudan I Red Dye in 2005 [21]

On 18 February 2005, the British Food Standards Bureau issued an alert to customers that products made by 30 companies, including Heinz, Unilever and McDonald's may contain Sudan I Red and ordered product recalls. On 4 March 2005, Beijing City regulatory inspection department detected Sudan I Red in chili paste made by Heinz, a preserved chili turnip from the Hunan Tan Xiang company and New Orleans chicken wings from KFC. The data published by the China Administration of Quality Supervision, Inspection and Quarantine (AQSIQ) showed that 88 food products from 30 companies in 18 provinces were adulterated with Sudan I Red. On 6 April 2008, the China National Center for Food Safety Risk Assessment (CFSA) published a risk assessment report on Sudan I Red in foods, which concluded that the risk of causing cancer was very low with low ingestion, however, it could lead to a risk of cancer with regularly intake [22].

24.2.4.3 Melamine in Infant Milk Powder in 2008 [23]

In 2008, many cases of kidney stones in babies were reported in Shandong, Gansu, Anhui, Hunan, Henan, Jiangxi and Hubei Provinces. All the babies were less than 12 months old. The investigations discovered the babies were fed with fake milk powder made by the San Lu Group and other infant formula companies. Melamine may have been added to the milk to increase the nitrogen content as indication of protein in milk to gain a higher price. In this melamine scandal, 39 965 babies had urinary tract stones, 12 892 were hospitalized and there were four deaths.

The San Lu group was fined 4.93 million RMB for producing and selling adulterated food products; its CEO was sentenced to life imprisonment and fined 2468 million RMB; three senior managers were sentenced to 5–15 years in prison; two were sentenced to death for selling the mixture of milk and melamine and several others were imprisoned as well.

24.2.4.4 Lean Meat Powder in 2011 [24]

In March 2011, China Central Television's consumer rights program "3.15" broadcast "Lean Pig Truth," which reported that Shinway's Jiyuan plant in Henan province bought pigs fed with lean meat powder (known to be the steroid clenbuterol). Thereafter, the Department of Public Security in Henan Province, together with food safety inspection authorities started a full investigation. Five people were sentenced for harming public security using dangerous practices: 39 for illegal sales; 52 for producing and selling toxic foods; 13 for neglect of duty; four for misuse of authority; one was given a suspended death sentence and one imprisoned for life. Overall, in 2011, 989 people were arrested from 105 counties in 17 provinces. The total amount of lean meat powder was near 39.5 tons.

24.2.4.5 Gutter Oil in 2011 [25]

In June 2011, "Xinhua News" reported on the business chain for gutter oil around Beijing, Tianjin and Hebei Provinces. The Ministry of Public Security then organized a nationwide movement to fight against gutter oil criminal activities, together with food safety authorities. This action lasted three months, with 128 cases tracked down, over

700 people arrested, 60,000 tons gutter oil seized, and over 60 networks in 28 provinces broken up.

24.2.4.6 Shanghai OSI Incident in 2014 [26]

On July 20, 2014, a Shanghai TV station reported that OSI used expired meat as a raw material to produce food. The Shanghai FDA and Department of Public Security immediately initiated an investigation to confirm the truth of the media report, shut down the plant, and seized the site, the raw materials and the finished products in the warehouse. OSI announced a recall of all the products from the market, which were destroyed under the control of the inspection authorities. Six employees were arrested.

24.3 The Current Status of Food Safety Regulatory Inspection

24.3.1 Basic Information

The statistical data indicate that there are 176 275 food manufacturers, 3463 food additive producers, 7.45 million food transportation and retail stores and 2.22 million catering service businesses [27].

24.3.2 The Status of Food Safety Regulatory Inspection

24.3.2.1 The Coordination Department and its Duties

On February 6, 2010, China's State Food Safety Commission (SFSC) was established under the State Council. Its main duties were to analyze the food safety situation; study, organize and guide overall food safety work; put forth major food safety policies and measures; and supervise and ensure the implementation of food safety regulatory responsibilities. The Vice Premier of the State Council serves as the director of the SFSC, which includes 15 members of government agencies. The Office of the SFSC performs the day-to-day work of the SFSC and the CFDA carries out the actual food safety work. This structure will be set up vertically from province to city, county and community level.

24.3.2.2 The Administration of Food Safety Inspection and its Duties

Once the State Food and Drug Administration is established, each province, city and county will form similar units. County-level food and drug administrations may set up dispatch offices in towns or specific regions. With this structure being set up, the holistic system will be completed and will perform the regulation and inspection of food and drug safety.

The revised China Food Safety Law of 2015 clarified that the CFDA conducts the overall inspection and management of food manufacturing, distribution and catering. The Health Administrative Department will carry out food safety risk monitoring and risk assessment, in conjunction with the State Council Food and Drug Administration departments to develop and publish national food safety standards. The State Administration of Quality Supervision, Inspection and Quarantine is responsible for regulatory inspection of the production of food-related products, and food import and export activity. The Ministry of Agriculture is responsible for the quality and safety of edible agricultural products and livestock slaughter regulation. The Ministry of Public

Security is responsible for food safety criminal investigation. The whole structure is shown in Figure 24.1.

Some provinces, cities and counties have been exploring comprehensive market regulatory reform. Industry and commerce, quality regulatory inspection, food and drug administration, prices and other departments are integrated to form a market inspection authority to conduct the corresponding market regulatory inspection duties.

24.3.3 The Current Status of the Food Safety Regulatory Inspection Mechanism

24.3.3.1 The Comprehensive Coordination Mechanism

The Food Safety Commission and the Office of Food Safety at all levels have established multi-level, multi-sectoral, comprehensive coordination mechanisms in many fields of food safety: strengthening inter-sectoral, inter-regional communication; bridging the connection between situation analysis, co-enforcement, administration and criminal justice, and accident response, and making concerted efforts together.

24.3.3.2 The Holistic Regulatory Mechanism

With respect to covering the food chain from farm to table, the MOA and the CFDA signed a cooperation agreement to establish a whole food chain regulation mechanism. Meanwhile, the new "China Food Safety Law" requires that the state establish full traceability of food safety systems, food producers and traders, to ensure that food sources can be tracked, risk can be controlled and responsibility can be taken.

24.3.3.3 Regulatory Mechanisms with Categories at Different Levels

To promote food production and the trading enterprise credit system, fully utilize regulatory resources, promote the implementation of corporate primary responsibility and to play the role of social regulatory inspection, food service units give public catering units a credit rating. In the doorway of the stores or on visible bulletin boards, the use of a cartoon face allows business food safety regulators to determine the frequency of its regulatory inspections in accordance with its credit rating. Some places have also explored a unified food credit grading and classification standards, built trustworthiness incentives, a dishonesty disciplinary mechanism and joint disciplinary mechanisms.

24.3.3.4 Emergence Management and Response Mechanisms

Government at all levels and food safety inspection agencies have developed a food safety incident emergence management plan, and completed food safety emergency management systems to strengthen emergency response capabilities.

24.3.3.5 Rewarded Reporting System

The CFDA has set up the "12331" food safety complaints hotline nationwide. This helps smooth the reporting system. In some places, the establishment of food safety reporting systems with prizes encourages people to participate in social monitoring food safety initiatives.

24.3.3.6 Primary Responsibility System

The new "China Food Safety Law" clearly states that food producers and traders are mainly responsible for the safety of their food production and operation, in accordance with the laws, regulations and food safety standards. Food manufacturers should make a commitment to show integrity and self-discipline, and accept social and public accountability.

24.3.3.7 Food Recall System

The "China Food Safety Law" requests the establishment of a national food recall system. Food producers and traders should immediately stop production operations, recall foods already on the market and inform consumers if the production and operation of the food does not meet food safety standards or there is evidence of possible harm to human health. If food producers and traders do not recall or cease operating in accordance with the provisions, the CFDA may enforce these actions.

24.3.3.8 Social Governance System

Food industry associations should promote standardized production and business activities, communicate food safety risk information and strengthen self-discipline through the development of industry standards, and self-regulatory and ethical principles. The media should enhance education on food safety knowledge, consumer awareness of food safety and self-protection and perform public social regulatory inspection.

24.3.4 Food Safety Regulatory Focus and Innovative Approaches

24.3.4.1 Edible Agriculture Sector

There is common agreement from all levels of food safety regulation that source management of food production is critical. In recent years, the MOA has started several innovative regulatory approaches focusing on: (i) cracking down on the illegal addition of toxic and hazardous substances, dead livestock purchase and slaughter, strict control of chemical fertilizers, pesticides, veterinary drugs and other agricultural inputs, the promotion of green pest prevention and safe handling of dead livestock; (ii) accelerating the traceability of edible agricultural products throughout the regulatory system.

24.3.4.2 Food Processing Sector

Food and drug regulatory authorities focus on high-risk food production enterprises in the food production chain to carry out special rectification, prevention and control of food safety risks including: (i) focus on high-risk foods such as infant formula, dairy products, meat, edible vegetable oil, bottled water and Chinese liquor, particularly cracking down on over-use of food additives and illegal non-food substances; (ii) strict supervision of infant milk powder production plants for sources of raw materials, production processes, product formulations and labeling, and traceability processes to enable comprehensive auditing; (iii) improvement of the access threshold for food entering the market, promotion of GMP, HACCP and whole-process management systems; (iv) strengthening risk monitoring and sampling to detect potential risks and establishing a recall system for unsafe food.

24.3.4.3 Food Trade and Service Sectors

The CFDA focuses on food distribution and catering services in which food safety risks have cumulative characteristics as they are at the end of the whole food supply chain. Several initiatives have been developed to: (i) strengthen routine supervision and management focus in risk management, and preventive control on high-risk issues, key areas and key periods; (ii) fully implement quantitative classification management and supervision of public food service units; (iii) explore the establishment of a catering enterprise violation score management system; (iv) strengthen the supervision of food safety network transactions through real-name registration of users on e-trading platforms.

24.3.4.4 Import Sector

The AQSIQ implements several important regulatory measures for imported food: (i) to study and evaluate the food safety regulatory systems of countries exporting food to China, and issue permits for their products to enter China; (ii) to establish record filing systems to ensure the safety of food exported to China, so that products from manufacturers with unsafe records will not be allowed into China.

24.3.5 Challenges of Food Safety Regulatory Inspection

24.3.5.1 Food Safety Problems are Subtle

In recent years, new food ingredients, new formulas, new business models, diversified food production and consumption, globalization of food production and trading have made food safety risk subtle and difficult to find and control.

24.3.5.2 The Food Company is not Able to Shoulder the Main Responsibility

The mindset of primary responsibility for food safety has not been developed, integrity is low, the management system is imperfect and, specifically, inadequate investment in food quality and safety is common. Unauthorized changes in the production process and illegally added fake substances are still happening.

24.3.5.3 The Problem of Food Safety Regulatory Inspection

1) There is a gap between standards and inspection needs
2) Coordination between regions, countries and local areas is difficult with the complicated food production and trading systems
3) The knowledge and skill of regulatory inspectors are not sufficient for them to perform professional inspections. Food safety inspection requires a better understanding of food safety risks and their occurrence at various points. Many inspectors come from different departments and lack basic food safety knowledge and experience; this cannot be changed in a short space of time
4) There is a need for inspection technologies
5) Food safety education and risk commutation need to improve
6) Principles such as risk management and whole-process control have not been well accepted. Finished-product testing by sampling from the market and reaction to rather than prevention of food safety incidents are still very popular.

24.4 The Future of Food Safety Regulatory Inspection

24.4.1 Trends in Regulatory System Development

The dynamics of food safety inspection systems indicates that regulation of the whole food chain is appropriate for the current situation in China. From a long-term point of view, food safety risk monitoring and assessment, and food safety standards development should be all integrated with regulatory inspection.

24.4.2 Trends in Regulatory Inspection Mechanisms

1) Risk management and whole-food-chain control will be the core principles. Regulation inspections will be based on risk assessment, management and coverage of the whole food supply chain.
2) Moving from single administrative regulation to social governance. The diversity and complexity of food safety risks require that all the stakeholders work together to develop a social governance mechanism to reduce food safety risks to the minimum level.
3) Moving towards a "system plus science and technology" regulatory model. The rapid growth of the "Internet" has changed the food production and trading world. The current traditional food safety regulatory approach can't meet the new economic situation. Use of big data and information technology should provide valuable tools for food regulatory inspection.
4) Integration of legal and ethical/credit systems. Safe foods are made by food companies, who should comply with legal requirement, as well as credit constraints.

24.4.3 Trends in What is Regulated and Inspected

1) Moving from inspection of "intentional violation by food companies" to "preventive control of food safety risks along the whole food chain." Currently food safety incidents in China are still mainly intentional violations due to loss of ethical standards. To prevent it from happening, the government has invested intensive resources, but progress has been slow. In the future, in addition to legal regulations, heavy punishments and the construction of a credit system, regulatory inspectors need to be focused on preventive and whole-process control to guide industry towards science- and risk-based management.
2) Prevention of microbial contamination will be the focus of food safety inspection. Food safety issues caused by microbial contamination are the top food safety hazards, both globally and in China, although the current situation of contamination by heavy metals, pesticide and drug residues, and the misuse and over-use of food additives will still be the main problems in China for a long time to come.
3) Inspection of food safety management systems will be the enhanced by inspectors. With the development of the food industry, food production and processing will be more reliant on management systems, and contamination and food safety incidents will be likely caused by a mistake in applying the systems during operation. Therefore, the future of food safety law enforcement inspection will pay more attention to food safety control systems (GAP, GMP, HACCP), their execution and corrective actions if problems occur.

24.5 Global Food Safety Regulatory Systems and their Relevance to China

When we describe the dynamics of China's food safety regulatory inspection, we thought it would be valuable to outline the global food safety systems in terms of comparison to understand and learn from them. Therefore, we introduce the following information mainly from the United States and European countries.

24.5.1 The Food Safety Regulatory System in the US [28–31]

Numerous federal, state and local agencies share responsibility for regulating the safety of the US food supply (Figure 24.2, Table 24.2). Federal responsibility for food safety is carried out primarily by the Food and Drug Administration (FDA), which is part of the US Department of Health and Human Services (HHS), and the Food Safety and Inspection Service (FSIS), which is part of the US Department of Agriculture (USDA). The FDA is responsible for ensuring that all domestic and imported food products, except for most meats and poultry, are safe, nutritious, wholesome and accurately labeled. The FDA also has oversight of all seafood, fish and shellfish products. FSIS regulates most meat and poultry, and some egg and fish products.

24.5.1.1 The Role of the USDA

The USDA inspects all meat, poultry and egg products sold in interstate commerce, and re-inspects imported meat, poultry and egg products to makes sure they meet US safety standards. The USDA's regulatory authority comes from the Federal Meat Inspection Act, the Poultry Products Inspection Act (PPIA), the Egg Products Inspection Act and the Humane Methods of Livestock Slaughter Act.

FSIS, under its current name since 1981, has been protecting public health since 1906, when the Federal Meat Inspection Act (FMIA) started. The Act began a system of continuous, daily organoleptic (sight, smell, touch) inspection in slaughterhouses to detect unsanitary conditions and adulterated products.

The 1967 Wholesome Meat Act and the 1968 Wholesome Poultry Products Act amended the FMIA and PPIA, extending federal requirements to imported products and to state meat and poultry inspection programs. These Acts ensure uniformity in the regulation of products shipped interstate, intrastate and in foreign commerce.

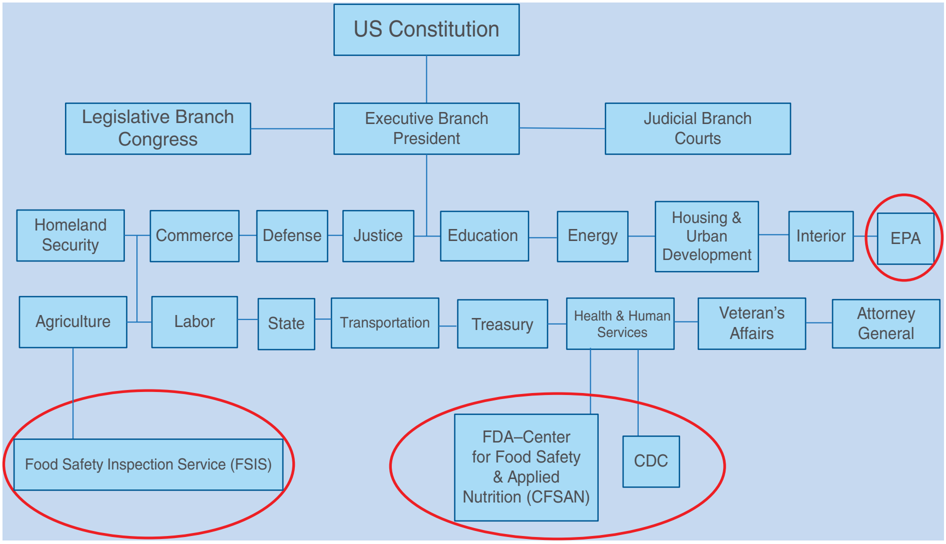


Figure 24.2 Food safety regulatory agencies in the USA (Ruth Petran, personal communication).

Table 24.2 Food safety regulatory agencies and their roles in the US. (From reference 28.)

Comparison of Selected Agency Responsibilites for Food Saftey and Quality

Agency	**Responsibility**
	• Dietary supplements
	• Bottled water
	• Seafood
	• Wild game ("exotic" meat)
	• Eggs in the shell
US Department of Agriculture (USDA)	• Grading of raw fruit and vegetables
	• Meat and Poultry
	• Eggs, processing and grading
	• Certifying organic production
National Oceanic and Atmospheric Administration	• Grading of fish and seafood
Environmental Protection Agency (EPA)	• Drinking water
	• Pesticide residues
Customs and Border Protection (CBP)	• Front-line enforcement and referral
Department of Justice (DOJ)	• Law enforcement
Federal Trade Commission (FTC)	• Advertising
Alcohol and Tobaacco Tax and Trade Bureau (TTB)	• Alcohol

Source: CRS, as adapted by N. D. Fortin, *Introduction to Food Regulation in the United States,* Part I, May 2008.

The Egg Products Inspection Act of 1970 required the USDA to ensure that egg products are safe, wholesome and accurately labeled. In 1995, responsibility for egg products inspection was transferred from the USDA's Agricultural Marketing Service to FSIS.

Another major change to meat and poultry inspection occurred when FSIS published the landmark Pathogen Reduction/Hazard Analysis and Critical Control Points (HACCP) Systems rule on July 25, 1996. Implementation of HACCP was completed in January 2000. Under HACCP, all slaughter and processing plants are required to adopt a system of process controls to prevent food safety hazards.

Also, the HACCP rule clarifies the respective roles of industry and government in ensuring food safety and, therefore, makes better use of government resources in addressing food safety risks. Industry is accountable for producing safe food. Government is responsible for setting appropriate food safety standards, maintaining vigorous inspection to ensure that those standards are met and maintaining a strong enforcement program to deal with plants that do not meet regulatory standards.

25.5.1.2 The Role of the FDA

The FDA, as authorized by the Federal Food, Drug and Cosmetic Act, and the Public Health Service Act, regulates about 80% of food, other than the meat and poultry products regulated by the USDA. The FDA is also responsible for the safety of drugs, medical devices, biologics, animal feed and drugs, cosmetics and radiation devices. The new egg rule giving the FDA the authority to inspect large commercial egg farms took effect on July 9, 2010.

The 111th Congress passed comprehensive food safety legislation known as the FDA Food Safety Modernization Act (FSMA). FSMA was the largest expansion of the FDA's food safety authorities since the 1930s. New rules governing the FDA's food inspection rules for both domestic and imported foods under the agency's jurisdiction have currently being developed and are under public review and comment.

The Center for Food Safety and Applied Nutrition (CFSAN), located in the Washington DC area, is responsible for: (i) conducting and supporting food safety research; (ii) developing and overseeing enforcement of food safety and quality regulations; (iii) coordinating and evaluating the FDA's food surveillance and compliance programs; (iv) coordinating and evaluating cooperating states' food safety activities and (v) developing and disseminating food safety and regulatory information to consumers and industry. CFSAN is very similar to the China Center for Food Safety Risk Assessment (CFSA).

The FDA's Center for Veterinary Medicine (CVM) is responsible for ensuring that all animal drugs, feed (including pet foods) and veterinary devices are safe for animals, are properly labeled and produce no human health hazards when used in food-producing animals.

The FDA also cooperates with over 400 state agencies across the nation that carry out a wide range of food safety regulatory activities. However, the state agencies are primarily responsible for actual inspection. The FDA works with the states to set the safety standards for food establishments and commodities and evaluates the states' performance in upholding such standards, as well as any federal standards that may apply. The FDA also contracts with states to use their food safety agency personnel to carry out certain field inspections in support of the FDA's own statutory responsibilities.

24.5.1.3 The Role of the CDC

The Centers for Disease Control and Prevention (CDC) leads federal efforts to gather data on food-borne illnesses, investigate food-borne illnesses and outbreaks, and monitor the effectiveness of prevention and control efforts in reducing food-borne illnesses. The CDC also plays a key role in building state and local health department epidemiology, laboratory and environmental health capacity to support food-borne disease surveillance and outbreak response. When a food safety problem arises, the FoodNet project, a collaborative effort among the CDC, ten states, the USDA and the FDA, is designed to help public health officials better understand the epidemiology of food-borne diseases in the United States.

24.5.1.4 The Environmental Protection Agency (EPA)

The EPA is responsible for regulating the use of pesticides on food. In cooperation with the states, it carefully regulates pesticides to ensure that their use does not compromise food safety. In particular, the federal pesticide program is designed to ensure that pesticides can be used without causing harm to the most vulnerable members of society, children and infants.

24.5.1.5 Food Defense against Bioterrorism

Following the terrorist attacks of September 11, 2001, the US federal food safety agencies began taking on the added responsibility of addressing the potential for deliberate contamination of agriculture and food products – bioterrorism. The Homeland Security Act of 2002 established the Department of Homeland Security, which now provides overall coordination for protecting the US food supply from deliberate contamination.

24.5.2 European Food Safety Regulatory Systems [32]

Since the 1996 British BSE crisis, a succession of high-profile food scares has shaken consumer confidence in the safety of food products. In the European Union (EU) these food scares were the major driving force for the establishment of food safety legislation and infrastructure in order to restore confidence in the food supply chain.

Food safety controls, systems and legislation have been set up across the EU, which aim to control food safety hazards in the supply chain to minimize the risk to consumer health. The EU has established a comprehensive food safety strategy, which ensures that the traceability of food must be established at all stages of production, processing and distribution. This requirement relies on a 'one-step back and one-step forward' approach, which implies that food business operators have in place a system enabling them to identify their immediate supplier(s) and their immediate customer(s). The high standards apply to food produced inside the EU and to food imports. The EU food strategy has three core elements: (i) food safety legislation, (ii) sound scientific advice on which to base decisions and (iii) enforcement and control.

24.5.2.1 Food Safety Legislation

Legislation in the EU is comprehensive and covers food, animal feed and extends to food hygiene, and it applies the same high standards across all EU countries. The general rules for all food and feed are supplemented by special measures in areas where specific consumer protection is necessary, such as the use of pesticides, food supplements, colorings, antibiotics or hormones. There are specific standards that apply to adding vitamins, minerals and similar substances to foods. The legislation also extends to products in contact with foodstuffs, such as plastic packaging.

In 2006, an important development in food safety legislation was the introduction of the 'Hygiene Package.' This term refers to a group of EU regulations that represent a re-organization of the regulatory framework for food hygiene and safety. These regulations clearly place the responsibility for food safety and hygiene across the entire food chain on the food business operator, whatever position they occupy in the food production chain. Policing of these obligations is carried out by a number of government agencies (usually Food and Veterinary Offices) involved in various regulation and enforcement activities. The Hygiene Package builds on general food law established by EC Regulation 178 of 2002. This regulation also provided the legal basis for the Rapid Alert System for Food and Feed (RASFF). This system has been operating within the European Community since 1979, but it was the publication of the General Food Law that gave the RASFF legal status. The RASFF is primarily a tool for exchange of information between the central competent authorities for the regulation of food and feed in the member states in cases where a risk to human health has been identified and measures are needed, such as withholding, recall, seizure or rejection of the products concerned.

When it comes to food contaminants, EU legislation stipulates that food containing an unacceptable level of any contaminant cannot be put on the market. There are also maximum levels set for some contaminants of greatest concern to EU consumers, either due to their toxicity or their potential prevalence in the food chain. These include aflatoxins, heavy metals (such as lead and mercury), dioxins and nitrates.

24.5.2.2 The European Food Safety Authority (EFSA)

Most of the EFSA's work is undertaken in response to requests for scientific advice from the European Commission, the European Parliament and EU Member States. The EFSA provides advice when legislation is being drafted and when policymakers are dealing with a food safety scare. It also carries out scientific work, in particular to examine emerging issues and new hazards.

24.5.2.3 Enforcement and Control

The EU Commission enforces feed and food law by checking that legislation has been properly incorporated into national law and has been implemented by all EU countries, and through on-the-spot inspections in the EU and outside. This work is carried out by the Food and Veterinary Office (FVO). The FVO may check individual food production plants, but its main task is to check that both EU governments and those of other countries have the necessary procedures in place for checking that their own food producers are sticking to the EU's high food safety standards. The FVO also plays a key role in the development of EU policy in the food safety, veterinary and plant health sectors.

24.5.3 The Relevance to China's Food Safety Regulatory Inspection Systems

With the information illustrated above, together with several chapters related to food safety regulations in this book, we would take into considerations the following points for further discussion in the continuous improvement of China's food safety:

1) Food safety regulatory inspection bodies need to establish effective and regular communication channels for better communication. Although China's food safety regulatory systems have been improved significantly towards coverage from farm to table by fewer authorities, such as the MOA, the CFDA and the AQSIQ, the lack of communication is still the issue. For example, the responsibility for inspection of primary products is sometimes not clearly defined between the MOA and the CFDA. Communication has not been regularly or smoothly conducted in terms of standards development. This generates misunderstanding and confusion in different standards; standards development is conducted over a short period of time and it is too rushed for it to be feasible and practical to complete it thoroughly [33]. Therefore, effective working mechanisms need to be established among these government branches.
2) The capability of inspection officers needs to be enhanced. In the US and the EU, there are many thousands of well-trained and qualified inspectors working in food processing plants to conduct routine and daily inspections, and working with the State Departments of Agriculture and Health or EU member countries closely. In China, many officials that perform similar jobs are not trained sufficiently to conduct enforcement in food safety, as it is often confused with quality concerns.

3) Inspection needs to be based on risk assessment. Risk- and science-based inspection is reliant on risk assessment and management; however, risk assessment results are still not reliable in China since some researchers conducting risk assessments do not fully understood the food processing practices, as they have no industry experience.
4) Holistic and comprehensive food safety management with all stakeholders has not been well performed. Communication platforms from government to industry and the public are not established, with much confusion existing currently. The functions of trade associations are still not well defined and therefore are not representing the food industry in dialogs with government and consumers [34].
5) The relationship between process control and finished product testing in food safety inspection is understood differently in different government branches [33]. Currently the CFDA are focused on random sampling and testing of products on the market or food served in restaurants. Weekly public notices for those companies whose products fail to meet the quality and safety requirement exerts strong pressure, forcing them to make corrective actions. This can be very powerful, but should be moved from these passive and costly projects to preventive process control using food safety management systems such as HACCP, GMP and SSOPs. It is good to see a movement towards whole process control as stated in the recently published "Regular food safety inspection checklist for food processing, trading and service" [35].

In summary, China's food safety is experiencing similar situations to the US and EU countries over a century ago. The history and development of food safety regulatory inspection systems from the two developed regions provide very helpful learning materials for China to develop its own effective and feasible systems. It is pleasing to see the progress that China has made in less than ten years. We feel very positive about further continuous improvement of China's food safety inspection systems and its overall food safety advancement in the years to come.

References

1 Xu Chen, Mingqiang Xie. 2013. *Food Safety Regulatory Inspection for Restaurants*. China Medical Science Press: Beijing [in Chinese].

2 FAO/WHO. 2003. Assuring Food Safety and Quality: Guideline for Strengthening National Food Control System. FAO/WHO: Rome.

3 China People's Congress 2015. Food Safety Law, People's Republic of China. http://www.npc.gov.cn/npc/cwhhy/12jcwh/2015-04/25/content_1934591.htm (accessed November 2016) [in Chinese].

4 Zhenhu Gu. 2009. Review of last 30 year's food hygiene inspection development in Shanghai. *Journal of China's Food Hygiene* (21)4, 299–303 [in Chinese].

5 Jianchen Zhang. 2013. The historical dynamics of China's food safety regulatory inspection systems, actual evaluation, and the future direction. *Journal of Henan Finance and Law University* (4), 90–98 [in Chinese].

6 Yang Han and Chenggui Li. 2011.The past, present and future of China's food safety. *Beijing, Reference of Economics Research* (45), 2–8.

7 Xinhua News. 1965. Food Hygiene Management Provisions (trial). China State Council. http://news.xinhuanet.com/ziliao/2005-02/02/content_2538913.htm (accessed November 2016) [in Chinese].

8 State Council. 1979. China's food hygiene provisions. http://fgk.chinalaw.gov.cn/article/xzfg/197908/19790800268290.shtml. (accessed November 2016).

9 People's Congress. 1982. China's Food Hygiene Provision (trial). http://www.flzx.com/fagui/zhongyang/201301/46735.html (accessed November 2016) [in Chinese].

10 People's Congress. 1995. China's Food Hygiene Law. http://www.sda.gov.cn/WS01/CL0056/10777.html (accessed November 2016)

11 State Council. 2004. Enhancement of food safety plan issued by State Council. http://fgk.chinalaw.gov.cn/article/fgxwj/200409/20040900277000.shtml (accessed November 2016) [in Chinese].

12 People's Congress. 2009. China's Food Safety Law. http://www.gov.cn/flfg/2009-02/28/content_1246367.htm (accessed November 2016) [in Chinese].

13 China's Government Organization. 2010. The notice of establishment of food safety committee office. http://www.scopsr.gov.cn/bbyw/dfjgbzxxkd/201012/t20101206_157536.html (accessed November 2016) [in Chinese].

14 China's Government Organization. 2013. The set of China's FDA's responsibilities and its employee positions. http://www.scopsr.gov.cn/zlzx/zlzxlsyg/201409/t20140929_266637.html (accessed November 2016) [in Chinese].

15 National Committee of Health and Family Planning. 2006. The notice of results of hygiene inspection on foods and cosmetics. http://www.nhfpc.gov.cn/zhuzhan/zcjd/201304/4af17f9c76824291b18d7405f7a150c8.shtml (accessed November 2016) [in Chinese].

16 China News. 2012. Ministry of Industry and Information: The passing rate of good quality food must reach 97% in 2015. http://finance.chinanews.com/cj/2012/04-23/3838715.shtml (accessed November 2016) [in Chinese].

17 National Committee of Health and Family Planning. 2006. The public notice of food poisoning in 2005 by Ministry of Health. http://www.nhfpc.gov.cn/zhuzhan/zcjd/201304/abbede83f3ac4a6384450f5442da0150.shtml (accessed November 2016) [in Chinese].

18 National Committee of Health and Family Planning. 2015. The public notice of food poisoning in 2014 by National Health and Family Planning. http://www.nhfpc.gov.cn/zhuzhan/bottom/bottom_wsb.html?WebShieldSessionVerify=dlVTtzM0XtGHmGJRehAI (accessed November 2016) [in Chinese].

19 Ministry of Public Security. 2011. Revision of China's Criminal Law (8th edition). http://www.china.com.cn/policy/txt/2012-01/14/content_24405284_3.htm (accessed November 2016) [in Chinese].

20 Legal System Daily, May 17, 2004. The fact of Fuyang faked milk powder indicating the products contained cheap starch and sugar which caused 12 infant's lives [in Chinese].

21 Legal Consulting. 2005. The urgent notice on testing and inspection of foods containing Sudan I by China's Administration of Quality Supervision, Inspection, and Quarantine. http://www.51wf.com/law/194078.html (accessed November 2016) [in Chinese].

22 China National Center for Food Safety Risk Assessment. 2008. Report of risk assessment on Sudan Red. http://www.cfsa.net.cn/ewebeditor/uploadfile/20120315201132442.pdf (accessed November 2016) [in Chinese].

23 Baidu. China's Dairy food safety incidences. http://baike.baidu.com/link?url=6ZeIov1mRf4ncwTEOePCJ0P_lFSmv_QCvsYANCHKW6yrKPQUxqktyYjfkKHQ1Bm3xcZ6qUfhBHKKadteH4d_RNk5yAp24uHjJq8V-B9Vep3nZtdHyoV3QnKEohyfAIjyIII6TKh_EBGRpzNgX_cekuxhRq7IGJJFylsh9AbYFxu (accessed November 2016) [in Chinese].

24 China's Internet Television. 2011. CCTV's special action of 315: Shine way's Clenbuterol scandal. http://jingji.cntv.cn/20110315/106477.shtml (accessed November 2016) [in Chinese].

25 Xinhua News. 2011. The iceberg of gutter oil around Beijing, Tianjing, and Hebei province. http://news.xinhuanet.com/politics/2011-06/30/c_121603125.htm (accessed November 2016) [in Chinese].

26 Chunying Xin and Wei Huang. 2015. *The Reading of China's Food Safety Law*. Beijing: China's Legal System Press. pp. 512 [in Chinese].

27 China FDA. 2014. Data searching. http://app1.sfda.gov.cn/datasearch/face3/dir.html (accessed November 2016) [in Chinese].

28 Renée Johnson, 2014. The Federal Food Safety System: A Primer. https://www.fas.org/sgp/crs/misc/RS22600.pdf (accessed April, 2016)

29 Susan Keenan, Stephen Spice, Jonathan Cole and Paola Banfi. 2015. Food Safety Policy and Regulation in the United States. http://www.europarl.europa.eu/RegData/etudes/STUD/2015/536324/IPOL_STU(2015)536324_EN.pdf (accessed May, 2016).

30 Selected Federal Agencies with a Role in Food Safety. http://www.foodsafety.gov/about/federal/ (accessed November 2016)

31 He Qian, Lin Lin and Ruilian Yu. Food safety regulatory inspection systems in the USA. Chapter 6 in: *Food Safety Law, Regulations, and Standards*, ed. He Qian, Lin Lin, and Ruilian Yu. 2014 [in Chinese].

32 Rongfang Chen and Jie Li. 2010. The study of European Union food safety regulatory system and its implication to China food safety. *Regulation Study-Shanghai FDA*: 2010:104 [in Chinese]..

33 Zhutian Wang, Yongxiang Fan and Zhe Zhang. 2016. Food safety standards. Chapter 19 in: *Food Safety of China: Past, Present and Future*, ed. Joseph Jen and Junshi Chen. China Science and Technology Press: Beijing, pp.238-250 [in Chinese].

34 Fred Gale and Sandra Hoffmann. 2016. Lessons from the development of U.S. Regulations. Chapter 21 in: *Food Safety of China: Past, Present and Future*, ed. Joseph Jen and Junshi Chen. China Science and Technology Press: Beijing, pp.263–278 [in Chinese].

35 CFDA. 2016. Measures of daily supervision and inspection of food production and operation. http://www.sda.gov.cn/WS01/CL0053/146520.html (accessed November 2016) [in Chinese].

25

Food Safety in Restaurants and Catering

Zhaohui Ma[1] *and Duncan Lap-Yan Tung*[2]

[1] *China Food and Drug Administration, China*
[2] *Center for Food Safety and Environment Hygiene Department, Hong Kong*

25.1 Introduction

In recent years, there have been gradual improvements in the living standards of national citizens, acceleration of the pace of work, a boom in the tourist industry and a continuous increase in the migrating population. More and more people dine out nowadays, and more and more restaurants are available. The catering industry in China is undergoing rapid development [1]. By the end of May 2015, the total number of catering service units in China had reached 3 233 000. Among them, the total number of fine dining restaurants, fast food restaurants, buffets and beverage shops reached 2 754 000. This is 23.5 times the total number of catering service units at the initial stage of the Chinese Economic Reform in 1978 – 117 000 [2].

Nowadays, the catering industry makes asignificant contribution to the national economy of China. In 2014, the national revenue from the catering industry was RMB 2786 billion, rising by 9.7% compared to the previous year [3]. According to the National Bureau of Statistics of China, in the first half of 2015, the national revenue from the catering industry was RMB 1,496.6 billion, rising by 11.5% compared to the same period in the previous year.

The catering industry is different from food production and distribution industries in terms of processing, marketing and trade practices. There are the following major differences: raw materials vary and their sources can be difficult to control; food-making processes are complex and there is a wide variety of dishes and pastries; food-making and consumption are immediate, so there cannot be any checking before consumption; catering service units are of different sizes, and some dealers do not have effective food safety management; employees are of high mobility, and most employees are of low educational level with a low awareness of food safety.

The catering service is the last segment in the food supply chain from farm to table, and the catering industry has its own characteristics and conditions. Food safety risks have the following features: (i) The risks can be accumulated and overlapped. Food safety risks from upstream in the food supply chain could be passed onto and accumulated at the downstream catering service. Different food materials may have the same or

Food Safety in China: Science, Technology, Management and Regulation, First Edition.
Edited by Joseph J. Jen and Junshi Chen.

Table 25.1 2005–2014 Food poisoning data from national catering service units.

Year	Overall food poisoning data			Food poisoning data for canteens			Food poisoning data for restaurants		
	No. of reported food poisoning cases	No. of poisoned persons	Death toll	No. of reported food poisoning cases	No. of poisoned persons	Death toll	No. of reported food poisoning cases	No. of poisoned persons	Death toll
2005	256	9021	235	62	3498	6	43	2982	0
2006	596	18063	196	237	8265	5	86	3837	3
2007	506	13280	258	142	5082	1	61	2984	4
2008	431	13095	154	162	5302	4	64	3042	2
2009	271	11007	181	50	2978	7	51	2821	5
2010	220	7383	184	37	2117	0	27	1621	3
2011	189	8324	137	44	2733	4	28	1516	3
2012	174	6685	146	42	3096	3	12	324	8
2013	152	5559	109	37	2388	3	22	1207	1
2014	160	5657	110	34	2139	2	30	1542	2
Total	2955	98074	1710	847	37598	35	424	21876	31

Source: Data is based on yearly notification of national food poisoning situation from national health administrations.

similar food safety risks, therefore food safety risks in catering are accumulated and overlapped. (ii) The risks are direct and visible. In comparison with other segments of the food supply chain, the catering service is customer-facing, and the accumulated food safety risks can be manifested more directly and collectively here, thus causing harm to public health, such as outbreaks of food-borne diseases. (iii) The risks are diversified and dynamic. In the catering industry, there are a wide variety of raw materials and products and food-making processes mostly involve manual effort, thus bringing in many potentially hazardous factors. (iv) The risks are preventable and controllable. Since food products in the catering industry need to be made and consumed immediately, a food safety inspection cannot be carried out before consumption. However, risks can come from different segments along the chain from raw materials to products. If hazardous factors in different segments can be identified early and effectively controlled, food safety risks can be prevented [4]. In addition, the catering service is closely related to people's everyday lives; society pays close attention to it and has high expectations of it. Therefore, food safety monitoring of catering services is one of the most important parts of overall food safety monitoring.

Food safety risks in the catering industry include not only risks from the food-making process in service units, but also risks transferred from the food supply chain covering planting, cultivation, production and sale of food raw materials. Therefore, the risks in the catering industry are the most prominent in the whole food industry. According to statistics from 2005 to 2014, health administrations in China reported 2955 public health emergencies, such as food poisoning, through the public health emergency direct reporting system. There were 98 074 morbidity cases and 1710 mortality cases; 1271 food poisoning cases (43.01%) occurred in canteens and restaurants, and among them, 59 474 people (60.64%) were poisoned and 66 (3.86%) died.

In particular, the food provided by central meal distribution units is usually consumed after storage and transportation procedures. High temperature and long duration of the storage and transportation is conducive to the cultivation of bacteria and the production of toxins. Once food is contaminated by pathogenic bacteria, it can easily lead to food poisoning. In addition, the amount of food supplied by central meal distribution units is usually very large. Once food poisoning occurs, it will affect a wide range of people. Therefore, central meal distribution units are always the focus of catering food safety monitoring.

For a long time, the Chinese government has been paying close attention to food safety monitoring, including food safety in catering. In January 1953, the State Council of China approved the establishment of disease prevention and control centers all over China, marking the start of the Chinese administration of food sanitation. From 1953 to 2009, health administrations had been responsible for the monitoring of food sanitation in catering (now called food safety in catering). In the past 50 years, thanks to the incessant efforts of health administrations, food sanitation, including catering food sanitation has been greatly improved. First, laws and regulations became more and more comprehensive. In the beginning, there were only administrative measures over particular varieties of food, but now there is a complete legal framework in place including the "Food Hygiene Law of the People's Republic of China" and more than 90 supporting regulations, covering monitoring of the catering industry, student meals, food and food raw materials, food packaging materials and containers, and related penalties for violation of regulations. Second, testing methods have become increasingly diversified.

A simple sensory testing method was replaced by qualitative tests, and then by quantitative tests, now conducted using cutting-edge equipment. Third, there was a yearly increase in the pass rates for random inspections of food facilities. The national pass rate rose from 83.10% in 1995 to 91.75% in 2003, an increase of 8.65%. Fourth, there was a declining trend in the total number of food poisoning cases and that of poisoned persons. In 1991, the total number of food poisoning cases was 1765 and poisoned individuals numbered 40 843. In 2003, the numbers dropped to 379 and 12 876, respectively, representing a 78.53% and 68.47% drop compared to 12 years ago.

25.2 Changes in Food Safety in Catering in the Past 10 Years

For the past decade, there have been significant changes in China's food safety in catering. On one hand, the operation modes and methods of the catering industry have altered remarkably, which has not only brought in new opportunities and new momentum for the improvement of food safety in catering, but also new problems and new challenges for its management. On the other hand, in order to cope with the new economy, society and industrial development, China has conducted a lot of beneficial exploration of aspects of regulations, framework and methods, and progress has been made in phases.

25.2.1 Changes in the Catering Industry

1) Chains have gradually become an important mode of business operation. In recent years, chain operation has become one of the most active business operation modes in the catering industry in China. With chain operation using unified brands, standards, distribution, management and services, catering service units are more and more standardized and professional. They usually have a higher standard of food safety management and make important contributions to the steady improvement of the Chinese catering food safety [5].
2) There has been a significant increase in the number of central kitchens. Following the development of in catering service chains, central kitchens have been developing rapidly. All products or parts of products in large-scale catering service units are produced in central kitchens [6]. By the end of May 2015, there were 1685 central kitchens all around China, established by chain catering enterprises. With independent sites and facilities, there is centralized production of the finished or semi-finished food products, with the direct distribution of products to catering service units [7]. Emerging central kitchens have adopted new features and built up new requirements for the catering industry, such as centralized purchase, centralized production, standardized operation, professional operation and scientific management. They are beneficial to further enhancement of the food safety level.
3) There has been an increase in the number of enterprises investing in the construction of a raw material base. In order to ensure food safety, more and more catering service units have improved the screening system for raw material suppliers, with strict implementation of unified purchasing of raw materials, and the development of a traceability system for raw materials. In addition, they have started to build a raw

material base for the planting of vegetables and fruits, and the cultivation of livestock and poultry, so as to control and reduce food safety risks.

4) There has been rapid development in takeaway and delivery services. According to analysis by the Chinese Cuisine Association, more than one-third of catering service units have launched takeaway and delivery services, which are developing rapidly. Food provided by takeaway and delivery services goes through many procedures from production to consumption and has a long storage time. Once it is contaminated by microorganisms, if it is stored for a long time at high temperatures, the micro-organisms will grow easily, multiply, produce toxins and lead to food poisoning. Therefore, the rapid development of takeaway and delivery services within the catering industry brings new problems to the management of food safety in catering.
5) Online marketing has gradually become the new impetus for industrial development. Apart from traditional catering, there is an increasing use of modern Internet technology for online ordering and reservation. With the increasing use and development of Online-To-Offline (O2O) modes in the catering industry, customers' food ordering and reservation habits have changed [8]. According to analysis by the Chinese Cuisine Association, the total number of online reservations at national restaurants exceeded 1.2 million in 2013, and the number of catering service units supporting online reservation rose 30-fold. Following thee rapid development of the catering network, food safety in O2O catering has attracted increasing attention from customers, becoming a new challenge for the government.

25.2.2 Changes in Monitoring of Food Safety in Catering

25.2.2.1 Changes in monitoring laws

"The Food Safety Law," commencing on 1 June, 2009 was a milestone for the legal system of food safety monitoring. The establishment of the system can be divided into two stages. In the first stage, "The Food Sanitation Law" and relevant laws, regulations and regulatory documents were enacted; followed by a second stage with the enactment of "The Food Safety Law" and relevant laws, regulations and regulatory documents.

Before 1 June 2009, on the basis of "The Food Sanitation Law," the national health administration of China promulgated a series of regulations and normative documents, including "Food Sanitation Management Methods for the Catering Industry," "Sanitation Supervision Methods for School Meals," "Sanitation Management Regulations for School Canteens and School Meals," and so on, in order to reinforce monitoring of food safety in catering. In 2005 particularly, the national health administration promulgated the "Sanitation Regulations for the Catering Industry and Collecting Meal Distribution Units" [9], which included detailed regulations for sanitation conditions, food-making and operation, sanitation requirements for employees and sanitation management of food production workshops in catering service units and central meal distribution units, thus pushing forward the improvement of food safety management in the catering industry.

After 1 June 2009, on the basis of "The Food Safety Law", the China Food and Drug Administration promulgated a series of regulations and specifications, such as "Management Methods for Catering Services," "Food Safety Supervision Methods for Catering Services," "Food Purchase Bill Management Regulations for Catering Services" and "Food Safety Operation Specifications for Catering Services," building up a new era regarding the legal framework of food safety monitoring. On 24 April 2015, China approved a revised version of “The Food Safety Law”, which came into operation on 1 October 2015. According to this revised version, the China Food and Drug Administration accelerated the improvement of “Regulations for Implementation of the Food Safety Law,” as well as the supporting regulations and normative documents. They will be put into effect together with the revision of “The Food Safety Law”.

25.2.2.2 Change in the Monitoring Framework

Since 2004, the catering food safety monitoring framework in China has undergone three stages of development and gone through two transformations.

The first stage was from 1 September 2004 to 31 May 2009. In this stage, according to the requirements of “The Decision of Further Reinforcing Food Safety Administration” issued by the State Council and “The Notice of Further Specifying the Issues Related with the Responsibilities of Food Safety Administrations” issued by the State Commission Office for Public Sector Reform (SCOPSR), China set up a monitoring mode by “putting monitoring-in-phases as the major role, and putting categorical monitoring as the supporting role.” In this mode of monitoring, the consumption sector, including the catering industry and canteens, was taken as a relatively independent segment of the food production and operation chain, and it was specified that different levels of health administrations should continue to undertake the responsibility for catering food safety monitoring [10, 11].

The second stage was from 1 June 2009 to 25 March 2013. In this stage, the monitoring mode of “putting monitoring-in-phases as the major role, and putting categorical monitoring as the supporting role” continued. The consumption segment, including catering services and canteens, continued to be taken as a relatively independent segment. However, according to “The Food Safety Law,” the segment was put under the monitoring of food and drug administrations. National and regional food and drug administrations took over the responsibilities of food safety monitoring in catering, but health administrations in Beijing, Fujian and some other cities and counties continued to undertake the responsibility for catering food safety monitoring because the transfer of responsibilities was yet to be completed.

The third stage was from 26 March 2013 to now. According to “The Plan for Organization Reformation and Function Change of the State Council” and “The Notice of the Organization Layout of the State Council”, China integrated food safety monitoring of food production, circulation and catering services and put responsibility onto the China Food and Drug Administration [12]. However, in Tianjin and some other cities and counties, newly built market administrations are responsible for monitoring of food safety in catering.

25.2.2.3 Changes in monitoring methods

Catering food safety administrations did not only inherit traditional monitoring methods like patrol inspection and random inspection, but also actively explored many new monitoring methods to deal with new situations. These methods mainly include:

1) *Risk monitoring methods.* In January 2010, five ministries and departments, including Ministry of Health, jointly issued the “Management Regulations for Food Safety Risk Monitoring (for Trial Implementation)” [13]. They gradually established a

food safety risk monitoring system covering the catering service segment; regular sampling, testing and analysis for food contamination, harmful factors in food, and other factors influencing food safety; timely identification of food safety problems; and provision of evidence for the decision-making and management of food safety risk. In 2013, the China Food and Drug Administration issued the "Management Standards for Food Safety Risk Supervision (for Trial Implementation)," "Rules for Sample Information Reporting and Inspection for Food Safety Risk Monitoring (for Trial Implementation)," "Management Rules for Food Safety Risk Monitoring and Inspection Organization (for Trial Implementation)" and "Technical Requirements for Sample Collection for Food Safety Risk Monitoring" [14], that collectively improved the risk monitoring system over the whole chain of food production and operation, including catering. It is now more scientific, systematic and standardized.

2) *Risk assessment methods.* In January 2010, the Ministry of Health and the Ministry of Industry and Information Technology jointly published the "Management Regulations for Food Safety Risk Assessment (for Trial Implementation)," which covered risk assessment for biological, chemical and physical hazards in food and food additives.
3) *Hierarchical monitoring.* Since 2002, catering food safety administrations have started quantitative and hierarchical management of catering service units [15, 16]. Quantitative assessment has been made of food safety conditions in catering service units. According to the assessment results, catering service units are divided into different food safety classes, and targeted monitoring measures are taken to facilitate standard management and trustworthy business operation. At the same time, monitoring resources are effectively used for continuous improvement of monitoring efficiency. By the end of 2014, this food safety ranking had been completed for 2 394 300 catering service units, accounting for 96% of all certified catering service units.
4) *Unannounced inspection.* Targeting disguised illegal food safety actions of catering service units, unannounced inspection was carried out by the China Food and Drug Administration in July 2012. Under certain conditions, unannounced field inspection can be made to check whether catering service units are providing a service that complies with the laws and regulations [17], in order to identify and solve serious catering food problems in time.
5) *Interviews with responsible persons.* In December 2010, the China Food and Drug Administration launched a system of interview with persons responsible for the food safety of catering service units [18]. Those in charge of catering service units with food safety accidents, serious illegal behaviors and failure to remove significant underlying risks of food safety were interviewed and required to take responsibility for food safety, immediately carry out effective measures, remove underlying risks in time and effectively improve the food safety level.

25.2.2.4 Changes in monitoring methods

Monitoring methods for food safety in catering undergone great development, with new monitoring methods featuring high technology, advanced information systems and a timely response being incorporated into different aspects of catering food safety monitoring.

1) Rapid testing technology is widely used. Following social development, sensory testing has fallen short of expectations in monitoring catering food safety. However, due to the limitations of testing capacity, testing amount, long testing period and high testing cost, testing services in laboratories cannot meet the demand for monitoring of food safety in catering. With the advantages of rapidity, convenience and sensitivity, rapid testing technology has been widely used in daily monitoring of food safety in catering and to ensuring food safety in important activities; it plays the role of preliminary screening [19]. The "Regulations for the Implementation of the Food Safety Law" issued in July 2009 provided a statutory role for the rapid testing method. It stated that monitoring departments can use rapid testing methods recognized by the food safety administration under the State Council to carry out preliminary screening of food. In June 2011, the China Food and Drug Administration issued "The Affirmation and Management Method of Rapid Testing of Food Safety in Catering Services," which standardized the use of rapid testing methods in the monitoring and legal enforcement processes of food safety in catering [20].
2) Remote monitoring technology is preliminarily applied. Administrations have begun to use modern technologies such as real-time remote video monitoring and real-time temperature monitoring of food safety in catering, especially in the assurance of food safety in high-risk units, sites and foods involving important activities. These technologies have been proven to be effective. At the 2008 Beijing Olympic Games, administrations used real-time remote video monitoring technology for the first time to safeguard food safety. Real-time remote monitoring was used for high-risk food-making processes in key regions, including the athletes' village and the media village. Improper food-making practices were found and rectified quickly, and so the underlying risks of food safety were eliminated [21]. In Expo 2010 Shanghai China, administrations used real-time monitoring with RFID technology to check the temperature of refrigeration storage, cold chain vehicles, and hot and cold box lunches , so as to eliminate underlying risks of food safety brought about by errors in temperature control [22].
3) Handheld mobile law enforcement devices are more widely used. In recent years, food safety officers in many regions have been equipped with handheld mobile law enforcement devices. With these, officers can access food safety databases in real time through mobile Internet when making daily patrol inspections. On the one hand, supervisors can retrieve monitoring records for catering service units and food safety laws and regulations. On the other hand, they can input and upload law enforcement documents, photos and videos to the terminal database, to facilitate timely data summarization, analysis and research.
4) An information network for monitoring is more well-established. In recent years, different regions in China have actively used information systems in the monitoring of catering food safety. There is emphasis on law enforcement, information monitoring, emergency management, public service and internal management. In addition, they also continuously enhance decision-making, law enforcement and emergency management capacities. At the same time, on the basis of existing electronic government and business systems, administrations are accelerating the construction of an improved catering food safety monitoring platform and implementing database connection and resource sharing [23].

25.2.3 Important Catering Food Safety Incidents

Since food safety risks in the catering industry can be accumulated, overlapped, and are direct and easily visible, food safety incidents such as food poisoning frequently occur. However, food provided by catering service units is made and consumed immediately, therefore there are relatively few regional and systematic risks within the catering industry.

Since 2004, most of the major catering food safety incidents reported by the media were not caused by the catering service itself. Some of them were caused by food safety problems or hidden troubles with raw material suppliers for some chain catering service units. For example, after the food safety scandal with raw meat and meat products from Shanghai Fusi Food Co Ltd in 2014, the food safety of many chain enterprises was questioned by the public. Some others incidents were caused by a lack of integrity in a few chain catering service units, because they misled customers in their business operation. For example, in 2011, Ajisen Ramen announced that the noodle soup was made from pig bone, but according to investigation, the noodle soup was from concentrate.

The incident with apple snails in Beijing was a representative incident caused by food safety problem in the catering service. On 11 August, 2006, Beijing Municipal Bureau of Public Health received a complaint that many customers had become ill after consuming apple snail salad. The bureau immediately contacted the 138 patients and investigated the two restaurants involved, and carried out administrative measures [24]. It was found that the disease was caused by *Angiostrongylus cantonensis* in the apple snails because they were not thoroughly cooked.

25.3 Current Food Safety in Catering

Different levels of food and drug administrations are now taking up responsibility for careful food safety monitoring. They are proactive in adopting innovative monitoring concepts, systems, mechanisms and methods, and pushing forward the development of food safety monitoring, so that national food safety in catering maintains an improving trend with stable progress.

25.3.1 The Revised Version of "The Food Safety Law" was Promulgated

On 24 April 2015, the National People's Congress of China approved the revised version of "The Food Safety Law," which further specified the principles of "prevention being the first priority, followed by risk management, whole-process control, and social co-governance," in order to establish the most stringent food safety monitoring system covering the whole process of food production and operation. The revision of "The Food Safety Law" represented one important step in legalization for food safety in China.

25.3.2 Construction of the Monitoring System was Pushed Forward

Starting from the reformation of the licensing system, the China Food and Drug Administration changed the inherent thinking of segmental monitoring, and integrated catering service licenses and food circulation licenses. At the same time, the China Food and Drug Administration conducted an in-depth investigation and drafted monitoring methods and standards for food operation covering the whole process of food circulation, catering service and agricultural products. Relevant laws and regulations will be issued in the second half of 2015 and 2016.

Food and drug administrations in different regions issued many targeted and practical monitoring regulations adapted on the basis of actual local situations. For example, Beijing issued "The Standard for Joint Investigation of Catering Service Licenses (for Trial Implementation)," which specified the investigation of catering service licenses and unified field inspection standards. Sichuan issued the "Management Methods for Food Safety of Student Canteens." Liaoning, Henan and Shaanxi issued methods or instructions for strengthening food safety management of dinner parties in rural areas. These local monitoring systems supplemented and enriched the overall food safety monitoring system for the catering industry in China.

25.3.3 The Use of Innovative Monitoring Methods

The Food and Drug Administration proactively performs research on new situations and new characteristics of the monitoring of food safety in catering, and explores innovative monitoring methods to enhance monitoring efficiency.

1) *Catering service units have actively built "open kitchens."* In recent years, some catering service units have built kitchens with a transparent glass wall. The food-making process can be seen by customers through a real-time video display, which has achieved good economic benefit and social responsibility. Adapting to new situations, regional food and drug administrations took open kitchens as an effective measure for catering service units to strengthen their food safety management and for achieving social co-governance of food safety. They actively promoted this measure and it gained recognition by the public. In 2014, on the basis of many successful regional experiences, the China Food and Drug Administration pushed forward the construction of "open kitchens" by catering service units. The action facilitated the fulfillment of food safety responsibility by catering service units, reinforced monitoring of the food-making process, promoted social co-governance of food safety in catering and brought about the conversion of catering food safety monitoring from external discipline to self-initiated discipline.
2) *The coverage of quantitative and hierarchic management was continuously expanded.* Based on the achieved results, food and drug administrations continued to reinforce the quantitative and hierarchic management of food safety in catering and expanded the coverage of the work. By the end of 2014, the assessment of food safety ranking had been completed for 2 394 300 catering service units, accounting for 96% of all certified catering service units.
3) *The construction of a food safety traceability system was implemented.* In order to strengthen the risk management of food safety, food and drug administrations actively carried out the establishment of a food safety traceability system. With the use of technological means, the sources, uses and the accountability of food safety information covering the whole process from food production, storage, transportation, circulation to catering services can be traced and identified.

In addition, regional food and drug administrations further opened up their thinking and created innovative monitoring methods adapted for local situations. For example, Shanghai issued the “Tentative Score-based Management Method of Illegal Actions of Food Safety in Catering Services.” With yearly accumulated assessments, the scores of catering service units are recorded in the credit archives of food safety, and penalties given for different incidents, in order to expand the monitoring of catering service units during and after food safety incidents. In Jiangxi, Shandong, Hunan and Yunnan, there was a pilot implementation of a compulsory insurance system for food safety responsibility.

25.3.4 Continuous Strengthening in Monitoring

With the problem-oriented approach, as well as the targets of problem identification, researching problems and problem-solving, food and drug administrations have continuously strengthened daily inspection, made strict monitoring of the certified operation of catering service units, and discharged legal responsibilities and obligations. They paid attention to the inspection, prevention and control of underlying risks of food safety. A large number of illegal actions were identified and handled quickly.

In one operation, the “Four Food Safety Modernization Actions” for rural areas, serious problems of food producers and operators, such as poor awareness of licensing and bill claiming, failure to discharge duties to inspect incoming goods, and non-standardized and incomplete recording of inspections were identified and corrected; illegal actions of selling and using foods and food raw materials from illegal sources were strictly cracked down on. In different regions, 424 200 food producers, 3 868 800 food dealers and 142 900 wholesale markets and traditional markets were inspected; 253 600 inspections were carried out; 45 100 cases violating food laws were investigated and 749 of them were brought to the judicial authorities.

In the corrective actions for food safety problems in schoolyards and surrounding areas, 784 700 food sellers and 396 700 catering service units were inspected in different regions; 53 700 food dealers were found with severe problems or risks. Random inspection was made of 50 100 batches of food, in which 2 962 batches and 81 200 kg of foods and food additives were found not to meet food safety standards and requirements and were removed; 6 426 unlicensed food dealers and 10 500 street hawkers were banned and 46 food safety cases were brought to the judicial authorities.

25.3.5 Improvements in Monitoring Capacity

After the integration of divisions and functions, there are problems such as the lack of standards and poor capacity in the process of legal enforcement by grassroots administrators. The food and drug administrations are actively improving their monitoring capacity and making great efforts to improve the monitoring capacity of grassroots administrators. The China Food and Drug Administration conducted a special investigation over the standardization of monitoring and law enforcement at grassroots level, and held three training sessions, respectively for food safety monitoring after edible agricultural products entering market, food safety monitoring of food circulation and catering service, and food safety monitoring and risk management. Nearly 400 people from provincial-level and municipal-level food safety administrations were trained. Depending on the actual situation, regional food and drug administrations actively made management rules and standardized law enforcement actions. They also provided special training to continuously enhance the professionalism and monitoring capacity of their personnel.

25.4 The Future of Food Safety in Catering

The government of China is now placing great importance on food safety. Food safety is regarded as an important reflection of its administrative ability. Chinese President Xi Jinping has stressed many times that the highest standard, the strictest monitoring, the heaviest penalty and the most serious accountability should be imposed to ensure food safety for the benefit of the Chinese people. It is foreseeable that in future, the system will be further enhanced with stricter monitoring, heavier penalties and better assurances of food safety in the catering industry in China.

25.4.1 The Legal System will be More Comprehensive

The revision of "The Food Safety Law" further strengthened monitoring of food production and operation, and imposed more severe penalties for illegal actions. After issuing the revised version of the "Regulations for the Implementation of the Food Safety Law," with the revision of "The Food Safety Law" as the core, China will actively improve the food safety framework covering food production and operation licensing, monitoring, hierarchical and classified management, business self-inspection, food recall and online food monitoring. The national monitoring system for food safety in catering will be further improved on the current basis. Relevant regulations and requirements will be more comprehensive, accurate and effective.

At the same time, different regions will issue management methods for food-making workshops and food vendors. The regional monitoring system for food safety in catering will be further improved on the current basis. Relevant measures and requirements will be more specific and feasible.

25.4.2 Improvements in Risk Management

Risk management will be accorded higher priority in the overall work plans of food safety monitoring. Classified and hierarchic monitoring of food production and enterprises, including catering service units, will be put into practice.

Concerning food safety monitoring in catering industry, on the one hand, food and drug administrations will classify food safety risks into different levels, introducing different licensing requirements for catering service units producing food of different risk levels, and carry out classified administrative licensing, so as to improve the pertinence and scientific basis of administrative licensing. On the other hand, based on current quantitative and classified management, food and drug administrations will actively learn from the experiences of overseas practice in food safety monitoring. According to the food safety management level of different catering service units, they will scientifically assess the food safety risk level and carry out targeted monitoring with different frequencies and different requirements for those units, to further improve the efficiency of daily monitoring.

25.4.3 Whole-Process Monitoring will be Strengthened

From the macro perspective, food and drug administrations will monitor the safety of the whole food production and operation process from edible agricultural products entering the market, food production, storage, transportation and marketing, to the catering service, as well as the production and operation of food additives. The catering service is an important segment in the chain of food production and operation, and so the monitoring of food safety in catering will be considered as a part of whole-process food safety monitoring. It will be uniformly planned and implemented to form a complete chain of food safety monitoring from edible agricultural products entering the market to catering services.

From the micro perspective, food and drug administrations will control whole-process monitoring of food safety in catering services. They will gradually implement whole-process monitoring from the purchase of raw materials, transportation, storage, rough processing, food cutting and matching, and cooking, to serving.

25.4.4 The System of Food Traceability will be more Mature

On the one hand, according to "The Food Safety Law," the China Food and Drug Administration will work with other departments, such as agricultural administration to build a collaborative mechanism of food safety traceability for the whole process of food production and operation. At the same time, on the current basis, food and drug administrations will try to build a whole-process management system of food safety traceability for different types of food, which will cover national-, provincial-, municipal- and county-level administrations. Electronic management for product certificates, production licenses, bill claiming, and purchase and sales accounts will be created; interconnection of food safety databases such as food production and operating licenses, as well as inspection reports, will be implemented, so as to form a whole-process electronic tracability chain.

On the other hand, as stipulated in the "The Food Safety Law," catering service units should gradually build their own food safety traceability system. Some catering service units should collect and store their food safety information by electronic means or by virtue of a third party food safety traceability platform, in order to identify the sources and uses of food and implement the whole system of traceability.

25.4.5 Penalties for Illegal Practices will be More Severe

The revision of "The Food Safety Law" fully reflects the principle of strict prohibition of illegal actions. First, it strengthens the identification of crimes in relation to food safety. Criminals responsible for illegal actions will be called to account. Second, it strengthens the penalties for criminals. Criminals sentenced to imprisonment for the crime of food safety will be banned from food production, operation and management for life. Third, it strengthens the investigation of administrative responsibility, and increases detention penalties. Serious illegal actions such as adding non-edible materials into food will incur administrative detention. Fourth, it increases the amount of fines. The fine for illegal actions such as adding drugs to food rises to a maximum of 30 times that of the food price. Fifth, it increases penalties for repeated illegal actions. If a business incurs three administrative punishments, such as fines or warnings within a year, it will be ordered by the administration to close down and its license will be revoked. Sixth, it strengthens investigations of civil liability. A new liability system is introduced, that "the first facility serving the customer should give the compensation first." The punitive compensation system is improved. Besides, there is a strengthening of joint civil responsibility and civil responsibility for fabricating and spreading false information on food safety.

In the revision of “The Food Safety Law”, the above-mentioned supplementary rules jointly form an integral legal framework for prohibiting serious illegal actions. Following gradual enforcement of these rules, the penalty for illegal actions regarding food safety in catering services will be reinforced, and will have a significant authoritative effect on catering service units, so that their practices will be in compliance with the food safety laws. They will effectively take responsibility for food safety, strengthen internal food safety management, standardize food-making processes and continuously improve their own food safety level.

25.4.6 Improvements in Technological Support

First, the sorting and integration of national food safety standards will be preliminarily fulfilled, critical and urgent standards will be set or revised, and the basis national food safety standard system in accordance with national conditions and internationally accepted practices will be formed. The construction of a food risk monitoring network and the related capacity will be strengthened; an inter-departmental data sharing and analyzing mechanism for the monitoring of food safety risks will be preliminarily established and the degree of data utilization will be improved. The monitoring and evaluation of food safety risks will be more systematic and standardized.

Second, a scientific, fair, authoritative and efficient food safety inspection and testing system will be gradually established and improved. The national-level inspection and testing organizations will take a leading role, with the provincial-level inspection and testing organizations playing a core role and the municipal/county-level inspection and testing organizations playing a supporting role. At the same time, third-party inspection and testing organizations will be fully utilized. National inspection and test capacity will be able to meet the demand of food safety monitoring and industrial development.

Third, inspection and testing technologies and equipment meeting international standards will be actively introduced into China, and the innovation of domestic testing methods will be accelerated. In particular, the research and development of rapid testing technologies featuring reliability, rapidity, convenience and accuracy will be strengthened. Many testing methods, reagents and devices for rapid testing and emergent surveillance, with low cost, short testing time and high accuracy, will be developed and rapidly used in daily food safety monitoring. Mobile law enforcement devices will be more and more widely used by grassroots food and drug administrators in their daily law enforcement actions.

25.4.7 Monitoring Capacity will be Continuously Improved

There will be new progress in the construction of administrative monitoring teams and technical monitoring teams for food safety in catering. Following the principles of team expansion, optimizing team structure and improving human resources, food and drug administrations will constantly expand the size of catering food safety monitoring teams and continuously improve the monitoring capacity and monitoring level of the teams by means of resource integration, talent recruitment and training. Furthermore, law enforcement devices, such as law enforcement vehicles, tools for collecting evidence and rapid testing devices used by catering food safety monitoring teams will be more modernized.

25.4.8 Social Co-Governance will be Reinforced

Great efforts will be made by the government and relevant administrations to strengthen the monitoring of food safety. Policies to encourage and guide social co-governance of food safety will also be further improved. The social co-governance of food safety will be more and more institutionalized and there will be long-term implementation.

Under the social co-governance of food safety, the interests of different stakeholders in food safety will be further attracted and stimulated. Catering service units will have a stronger awareness of food safety and trustworthy operation, and their attitude towards the fulfillment of food safety responsibilities will turn from passive to active. More and more catering service units will consciously undertake legal liability, improve control of food safety in catering services, strengthen training for employees, reinforce control over food production processes and do their best to ensure food safety in catering services. In addition, there will be more engagement with the public to join in co-governance, the catering industry will further strengthen self-discipline and there will be enhancement of media monitoring.

25.5 Food Safety Regulatory Systems in Other Countries

25.5.1 Australia

The Australian Commonwealth, state and territory governments signed the Inter-Governmental Agreement on Food Regulation (the Food Agreement) in November 2000. This regulatory system sought to implement a cooperative national system of food regulation. The current Australian food regulatory system introduced a whole-government and whole-chain approach to food standards and policy guidelines in Australia [25].

There are three key bodies in Australia playing an overarching regulatory role in developing and setting food policies and regulations at the national level. They are the Australia and New Zealand Food Regulation Ministerial Council (the Ministerial Council); the Food Regulation Standing Committee (FRSC) and Food Standards Australia New Zealand (FSANZ)

Food standards developed by FSANZ are grouped together to constitute the Australia New Zealand Standards Code (the Code). The Code was gazetted in December 2000 to become the sole food code in Australia. It is given legal force through the Australian Commonwealth, state and territory food legislation. In 2007, the Food Standards Australia New Zealand Amendment Bill was passed to harmonize processes for the assessment of applications and proposals. There is other legislation that also has a food safety focus. The Imported Food Control Act 1992 provides for the inspection and control of food imported to Australia. The Export Control Act 1982 covers control of export of certain goods (e.g. animals, eggs, fish, meat, plants, hay, organic procedures and related products). The Quarantine Act 1908 provides for human, animal and plant quarantine to prevent the introduction of specified diseases into Australia and the spread of such diseases within Australia. The acts are administered and enforced by the Australian Quarantine and Inspection Service (AQIS). These food acts regulate the manufacture, transport and handling of food. The acts contain definitions of terms and offences, and matters relating to the administration and enforcement of the respective acts, regulations and food standards.

The Australian states and territories impose penalties for breaches of the food acts. The penalties are associated with four types of offences: (a) failure to give notice before commencing a food business, or operation of an unlicensed food business; (b) provision of unsafe food either unknowingly or deliberately; (c) obstruction of an authorized officer and (d) failure to follow a compliance order or directive. Financial penalties are most commonly used. Other enforcement tools include advice on the nature of the problem and remedies, verbal warnings, written warnings, formal rectification notices and fines, prosecution and closure orders.

Measures for food monitoring and surveillance are implemented at points of entry or production up to the distribution level. There is a food safety inspection programme known as the Imported Food Inspection Scheme (IFIS). Imported food is referred to AQIS for inspection by the Australian Customs Service to ensure that it meets Australian requirements for public health and safety, and complies with Australian food standards as detailed in the Code. AQIS applies a risk-based approach to border inspection, with priorities given to food products that FSANZ considers to pose a medium to high risk to public health. The inspection involves a visual or label assessment, and may also include sampling the food for analytical tests against a published list of potential hazards, such as micro-organisms and contaminants.

The Code sets out legal requirements to ensure that food products can be properly identified and traced to facilitate retrieval of unsafe food products from the market place. The Code states that a food business must provide the name and business address in Australia of the vendor, manufacturer or packer or, in the case of food imported into Australia, the name and business address in Australia of the imported product, to the reasonable satisfaction of an authorized officer upon request; and a food business engaged in the wholesale supply, manufacture or importation of food must have in place a system to ensure the recall of unsafe food. The businesses should have some record-keeping procedures showing the path of a particular food from suppliers through processing to customers.

25.5.2 The European Union (EU)

The EU food safety policy safeguards health along the whole agro-food-chain, including every part of the food production process from farming to consumption by preventing food contamination and promoting food hygiene, food information, plant health, and animal health and welfare.

The basic principles of the EU food safety policy are defined in the EU General Food Law adopted in 2002. The general objectives are to facilitate the free trading of food across all EU countries by ensuring the same high level of consumer protection in all Member States. It covers all parts of the food chain from animal feed and food production to processing, storage, transport, import and export, as well as retail states. All food and feed produced and sold in the EU can be traced from farm to fork. The EU food law also establishes the principles of risk analysis. These stipulate how, when and by whom scientific and technical assessments should be carried out in order to ensure that humans, animals and the environment are protected. The basic principles for the food safety policy include protection of public health, plant health and animal health and welfare; risk analysis and independent scientific advice; precaution; the possibility to trace the origin of all products; transparency and clear information on food and feed; clearly defined responsibilities for all sectors in the agro-food chain; strict controls and regular checks; and training and education [26].

The EU institutions are guided by the work of scientific committees and by independent scientific advice from agencies such as the European Food Safety Authority (EFSA). the EFSA was set up in 2002 and carries out risk assessments before certain foods are allowed to be sold in the EU.

Under EU rules, rigorous checks are carried out to ensure that all products entering the food chain meet the relevant standards. They include tests for harmful residues from veterinary medicines, pesticides and contaminants. EU inspectors also visit farms and businesses associated with the production of food to ensure that food and animals coming from outside the EU meet the European standards.

The EU Trade Control and Expert System (TRACES) is a system for tracking live animals and food and feed of animal origin as they enter the EU and are traded within the EU. It enables veterinary services and businesses to react swiftly when a health threat is discovered. Products are withdrawn from supermarket shelves quickly if needed.

The EU Rapid Alert System for Food and Feed (RASFF) was launched in 1979. It allows information on food and feed to be shared quickly and efficiently between all the relevant bodies at national and EU level. It helps governments to act in a quick and co-ordinated manner to avert food safety risks before consumers are harmed, for example by recalling products.

Strict and regular official controls are carried out by the EU Member State authorities to ensure that the EU's high standards for food and feed are met and maintained. Controls are carried out regularly on all the operators along the agro-food chain by independent and well-trained authorities. They use state-of-the-art techniques and methods and rely on a wide network of official laboratories for any test or analysis needed to verify compliance with the rules.

The EU border controls on plants, animals, food and feed imports are essential to safeguard animal, plant and public health. It ensures that all imports meet EU standards and can be placed on the EU market safely.

There is an EU training strategy designed to increase knowledge and awareness of EU food, plant and animal health and welfare laws. It is targeted at the people responsible for official controls along the food chain in countries inside and outside the EU.

25.5.3 The United States of America (US)

The Food Safety System of the US is the responsibility of the US Food and Drug Administration (FDA). The FDA is the food regulatory agency of the Department of Health and Human Services. One of the aims of the FDA is to protect public health by assuring that foods (except for meat from livestock and poultry) are safe, wholesome, sanitary and properly labeled. The US Department of Agriculture (USDA) regulates beef, poultry and processed egg products.

The FDA Food Safety Modernization Act (FSMA) was signed into law on 4 January 2011. It aims to ensure the US food supply is safe by shifting the focus from responding to contamination to preventing it [27]. The Act requires that facilities engaged in manufacturing, processing, packing or holding food for consumption in the United States submit registration information to the FDA. It provides the FDA with authority to suspend the registration of a food facility in certain circumstances. If the FDA determines that food manufactured, processed, packed, received or held by a registered food facility has a reasonable probability of causing serious health consequences or death to humans or animals, it may, by order, suspend the registration of a facility.

Under the provisions of US law contained in the US Federal Food, Drug and Cosmetic Act, importers of food products intended for introduction into US interstate commerce are responsible for ensuring that the products are safe, sanitary and labeled according to US requirements. Imported food products are subject to FDA inspection when offered for import at US ports of entry. The FDA may detain shipments of products offered for import if the shipments are found not to be in compliance with US requirements. Both imported and domestically produced foods must meet the same legal requirements in the US.

The FDA has developed a comprehensive Food Protection Plan to address the changes in food sources, production and consumption in today's world. The plan presents a robust strategy to protect the nation's food supply from both unintentional contamination and deliberate attack. The Food Protection Plan builds in prevention first, then intervention and finally response.

The FDA monitors domestic firms and the foods that they produce. It has multiple initiatives for monitoring products imported into the US. The FDA protects public health through research and methods development, inspection, sampling, recall, seizure, injunction and criminal prosecution. Food producers need to recall their products from the marketplace when they are mislabeled or when the food may present a health hazard to consumers because the it is contaminated or has caused a food-borne illness outbreak. When the FDA finds that a manufacturer has violated regulations, it notifies the manufacturer in the form of a warning letter.

Sampling is an important part of the preventive approach, rather than solely responding to outbreaks of food-borne illness. This is part of the FDA's efforts to protect the food supply by keeping contaminated food from reaching consumers. The FDA will publicly share the data it receives through this approach and will engage stakeholders throughout the process. Surveillance sampling is one type of sampling that is important for food safety. The methods that the FDA uses fall into three broad categories: environmental, product and emergency response/emerging issues sampling. If potentially harmful contaminants are found in a product that has been distributed or is actually on the market, the FDA will consider regulatory and enforcement options, including encouraging a voluntary recall, ordering a mandatory recall, ordering administrative detention to prevent the product from being distributed and/or issuing public warnings to alert customers to the potential danger. If potentially harmful contaminants are found in samples taken from imported food, the shipments may be detained and refused entry, and future shipments may be subject to an Import Alert as warranted.

References

1 Ministry of Health of the People's Republic of China. (2007) *Food Safety Supervision*, pp. 322.
2 The Office of Statistics of the China Food and Drug Administration. (2015) *The Statistics Report of Food and Drug Supervision* (H1 2015), pp.1.

3 Chinese Cuisine Association. (2015) *2014 Chinese Catering Market Analysis and 2015 Forecast*, pp.1–3.

4 Personnel Department and Institute of Advanced Study of the State Food and Drug Administration. (2013) *Supervision of Food Safety in Catering Services*, pp.7–8

5 State Food and Drug Administration. (2012) *The Notice of Further Strengthening the Food Safety of Chain Catering Service Businesses*, http://www.cfda.gov.cn/WS01/CL1605/70340.html (accessed November 2016).

6 Chinese Cuisine Association. (2014) *Chinese Catering Industry Development Report* (2014), pp. 69–78.

7 State Food and Drug Administration. (2011) *The Notice of Issuing Licensing and Investigation Standard for Central Kitchens*, http://www.cfda.gov.cn/WS01/CL1605/62423.html (accessed November 2016).

8 Chinese Cuisine Association. (2014) *Chinese Catering Industry Development Report* (2014), pp.30–36.

9 Ministry of Health of the People's Republic of China. (2005) *The Notice of Issuing the Standard for the Hygiene of Catering Industry and Collective Meal Distribution Units*, http://www.nhfpc.gov.cn/zhuzhan/wsbmgz/201304/2500f76bee744c198ec4ccf2788cd387.shtml (accessed November 2016).

10 The State Council of the People's Republic of China. (2004) *The Decision of Strengthening Food Safety Administration*, http://www.gov.cn/zwgk/2005-08/12/content_22130.htm (accessed November 2016).

11 State Commission Office for Public Sector Reform. (2004) *The Notice of Further Specifying the Functions and Responsibilities of Food Safety Administrations*, http://www.chinalawedu.com/news/1200/22598/22621/22922/2006/3/wa329673091513600210101-0.htm (accessed November 2016).

12 The State Council of the People's Republic of China.(2013) *The Notice of Sector Setting*, http://www.gov.cn/zwgk/2013-03/21/content_2359435.htm (accessed November 2016).

13 Ministry of Health, Ministry of Industry and Information Technology, State Administration for Industry and Commerce, and General Administration of Quality Supervision, Inspection and Quarantine of China, State Food and Drug Administration. (2010) *The Notice of Issuing The Management Rules for the Monitoring of Food Safety Risks (for Trial Implementation)*, http://www.nhfpc.gov.cn/sps/s5853/201002/df6c5689c712424fadfbbe87045663c5.shtml (accessed November 2016).

14 China Food and Drug Administration.(2013) *The Notice of Issues of Four Documents of Management Standards of the Monitoring of Food Safety Risks (for Trial Implementation)*, http://www.sdfda.gov.cn/art/2014/4/30/art_153_46263.html (accessed November 2016).

15 Ministry of Health of the People's Republic of China. (2002) *The Notice of Carrying out Quantitative and Hierarchic Management System of Food Hygiene Supervision*, http://www.tech-food.com/kndata/detail/k0001999.htm (accessed November 2016).

16 State Food and Drug Administration. (2012) *The Guidance for Carrying Out Quantitative and Hierarchic Management of Food Safety Supervision for Catering Services*, http://www.cfda.gov.cn/WS01/CL1605/68355.html (accessed November 2016).

17 State Food and Drug Administration. (2012) *The Notice of Issuing a Tentative Method for Unannounced Inspection of Food Safety*, http://www.cfda.gov.cn/WS01/CL1605/73895.html (accessed November 2016).

18 State Food and Drug Administration. (2010) *The Notice of Establishing the System of Interview with Responsible Persons for Food Safety of Catering Service Units*, http://www.cfda.gov.cn/WS01/CL1605/57162.html (accessed November 2016).

19 The Command Center of Public Hygiene Guarantee for Stadiums of the Olympic Games under Beijing Municipal Bureau of Public Health. (2008) *Public Hygiene Guarantee for Stadiums of Beijing Olympic Games 2008: Policies*, pp. 379.

20 State Food and Drug Administration.(2011) *The Notice of Issuing the Affirmation and Management Method of Rapid Inspection over Food Safety in Catering Services*, http://www.cfda.gov.cn/WS01/CL1605/63570.html (accessed November 2016).

21 The Command Center of Public Hygiene Guarantee for Stadiums of Olympic Games under Beijing Municipal Bureau of Public Health. (2008) *Public Hygiene Guarantee for Stadiums of Beijing Olympic Games 2008: Stadiums*, pp. 325–342.

22 Personnel Department and Institute of Advanced Study of State Food and Drug Administration. (2013) *Technical Supervision of Food Safety in Catering Services*, pp. 247–251.

23 State Food and Drug Administration. (2012) *The Notice of Fulfilling the State Council's Order to Strengthen Supervision of Food Safety in Catering Services*, http://www.cfda.gov.cn/WS01/CL1605/74104.html (accessed November 2016).

24 Ministry of Health of the People's Republic of China. (2006) *The Notification of Praise for the Department of Health of Zhejiang Province Cracking Down on Poor-Quality Cooking Oil and Beijing Municipal Bureau of Public Health Handling the Case of Foodborne Disease Caused by Apple Snails*, http://www.gov.cn/gzdt/2006-10/17/content_415050.htm (accessed November 2016).

25 Department of Health and Ageing, Australian Government. (2009) *Australian & New Zealand Food Regulation Enforcement Guideline Version 8*, https://www.health.gov.au/internet/main/publishing.nsf/Content/270D88C279EB298DCA257BF0001C96FA/$File/7B.%20Australia-and-New-Zealand-Enforcement-Guideline.pdf (accessed November 2016).

26 European Union. (2014). *The European Union Explained: From Farm to Fork: Safe and Healthy Food for Everyone.* http://europa.eu/pol/index_en.htm (accessed November 2016).

27 US Food and Drug Administration. http://www.fda.gov/Food/default.htm (accessed November 2016).

26

Food Safety and International Trade: Regulatory Challenges

Shawn S. Arita[1]*, Fred Gale*[1] *and Xuedan Mao*[2]

[1] *Economic Research Service, Department of Agriculture, China*
[2] *China National Center for Food Safety Risk Assessment, China*

26.1 Introduction

China's entry to the World Trade Organization (WTO) and its recent rapid economic development has led to growing demands for agricultural imports. While liberalization of trade expands opportunities for agricultural trade it also presents new regulatory challenges in the area of food safety. WTO members must use regulatory practices that are both transparent to trading partners and based on non-discriminatory, scientific principles. Globalization also introduces foreign technologies that add new complexities for monitoring food safety and risk assessment to China.

This chapter discusses the regulatory challenges facing China's food safety regulators as the country engages with complex, dynamic, international markets. The first part of the chapter provides an overview of changes in China's Sanitary and Phytosanitary (SPS) regime since WTO accession. China has revised food safety regulations, reorganized regulatory structures, and established notification and enquiry point mechanisms to increase transparency. While China has made its trade policy more compliant with WTO transparency guidelines, the lag in development of specialized staff and bureaucratic divisions has limited the effective functioning of these new structures. The volume of notifications and comments has stretched limited staff resources. Despite the establishment of expert networks, staff has had difficulty responding to complex concerns raised by trading partners.

The second part turns to an in depth case study of China's experience regulating beta agonists, a family of compounds that can increase the efficiency of livestock production when mixed with animal feed or water. Beta agonists are emblematic of the complex challenges China's food safety regulators face in balancing new technologies, demands for efficiency, monitoring and enforcement, risk analysis, and foreign trade. When Chinese regulators first began to grapple with poisonings linked to beta agonists, nearly all of the country's pork was supplied domestically. Authorities have since then struggled to control use by domestic producers. Now, a significant share of China's pork is

---

Note: The views expressed in this article are those of the authors and do not necessarily reflect positions of the US Department of Agriculture or the Economic Research Service.

Food Safety in China: Science, Technology, Management and Regulation, First Edition.
Edited by Joseph J. Jen and Junshi Chen.

imported, and differing assessments of the risks posed by beta agonists raise complexities for food safety regulators in this growing trade. The case study reflects the challenges facing food safety regulators as the food system modernizes and integrates with global markets.

26.2 Overview of China's SPS regime

By joining the WTO in 2001, China's agri-food system committed to a more open market and to new disciplines on its food safety regulatory practices. Under the WTO's SPS agreement [1], countries may take measures to protect human health against threats arising from additives, contaminants, toxins, and diseases in food and beverages, as long as they are based on scientific principles and are non-discriminatory.[1] The SPS agreement was an attempt to balance the rights of a country to protect food safety and minimize the costs on trade. Harmonization of standards, equivalence of measures, risk assessment, and transparency were key guidelines of the agreement.

26.2.1 Authority Organizations of WTO/SPS in China

China has made progress in making its trade policies compliant with the WTO. An initial step was to organize government departments in accordance with the requirements of the WTO/SPS Agreement to facilitate communication with other WTO members on food-safety-related matters and standards. China set up a WTO/SPS notification authority at the Ministry of Commerce, which is responsible for external notification of Chinese SPS measures. A WTO/SPS notification and enquiry point at the General Administration of Quality Supervision, Inspection, and Quarantine (AQSIQ), is responsible for responding to SPS consultations made by other WTO members, consulting other WTO members on behalf of Chinese governmental agencies, industry associations, enterprises, and individuals.

The National Health and Family Planning Commission (NHFPC), the Ministry of Agriculture (MOA), the China Food and Drug Administration (CFDA), and other related departments are responsible for the technical issues relevant to respective obligations. For agricultural products, the MOA set up an agricultural contact point for WTO/TBT-SPS national notification and an enquiry point at the Institute of Agricultural Quality Standards and Testing Technology, Chinese Academy of Agricultural Sciences in 2005, which is responsible for WTO/TBT-SPS notification and comments, regular SPS meetings, and other issues related to agricultural products. In April, 2014, the NHFPC set up a WTO Project Management Office at the National Center for Food Safety Risk Assessment (CFSA) under the National Center for Food Safety Risk Assessment, which is responsible for the notification and comments, and other SPS related issues on WTO/SPS measures relevant to food safety. Since China's entry to the WTO, all ministries and commissions have established WTO/SPS expert groups in various professional fields responsible for researching and appraising foreign SPS measures.

---

[1] In addition to human health, measures to protect animal and plant health from the entry or spread of plant- or animal- borne pests or diseases are also covered under the WTO SPS Agreement.

26.2.2 WTO/SPS Notification and Comments

From its accession in 2001 to March 2015, China notified 1055 WTO/SPS measures, including 985 regular notifications, 20 emergency notifications, and 40 addendum/corrigendum and translation supplementation notifications [2]. Food safety accounted for 85.5% of all SPS notifications. Before implementation of the *Food Safety Law* in 2009, technical regulations relevant to food safety, such as food hygiene standards, were either solely notified by the Standardization Administration of the People's Republic of China (SAC) or jointly announced with the original Ministry of Health. After the *Food Safety Law* was implemented, national food safety standards became the main content of SPS notification measures, notified by the NHFPC (the original Ministry of Health). From 2009 to 2014, China announced over 700 measures relevant to national food safety standards. The number of WTO/SPS measures notified in China has gradually ranked among the top three in the world, a reflection of how China has gradually increased transparency in fulfilling the WTO/SPS Agreement.

As the department responsible for the formulation of the national food safety standards, the NHFPC has collected WTO/SPS notifications into the procedure manual for the establishment and amendment of national food safety standards. The *Administrative Measures for National Food Safety Standards* [3] expressly stipulates that national food safety standards shall fulfill the obligation of notification to the WTO, which serves as the legal basis for the WTO/SPS notification of Chinese food safety standards.

Each year, China receives over 1000 SPS notification measures from other WTO members distributed by the WTO/SPS Committee [4]. After receiving the SPS notifications of each member, the WTO/TBT-SPS national notification and enquiry point of China distributes them to the AQSIQ, MOA, NHFPC, and other relevant departments based on the content of each notification. Each department organizes experts from their respective fields to put forward comment opinions. About 40 comments each year are submitted to WTO members, such as the European Union (EU), the United States, and South Korea [5]. The comments cover residues of pesticides and veterinary drugs in food, food-related laws and regulations, and other food safety standards and measures. Replies are received for some comments. However, only a very small percentage of the comments may have actually affected China's exports. Furthermore, China is currently lacking the technical resources to follow up on responses.

26.2.3 Overview of the Participation of China in WTO-SPS Discussions

As a member of the WTO, China has played an increasingly active role in SPS regular meetings. The Ministry of Commerce organizes delegations to attend the regular meetings of the WTO/SPS Committee, held three times each year. The Ministry of Commerce also leads trade policy reviews, which engage the AQSIQ, MOA, and other relevant departments and institutions to jointly study and put forward a list of questions regarding trade policies of other trade partners. These efforts are then collated and summarized by the World Trade Department of the Ministry of Commerce and officially submitted to the WTO/SPS Committee.

Through the WTO, China has become more active in multilateral trade issues concerning food safety measures. For example, China undertook the drafting of definitions in SPS-related private standards, served as chair of the electronic working group of SPS-related private standards, and has worked together with New Zealand as a co-chair regarding the organization and drafting of definitions in SPS-related private standards. The measure received recognition and support from the majority of WTO members.

China has raised nearly 20 specific trade concerns related to food safety with other WTO members [6]. Prior to 2005, the concerns were focused on Japanese and EU pesticide-residue-related measures that have affected the export of Chinese tea and other agricultural products. After 2009, concerns were raised about the proposed US Food Safety Modernization Act. China had difficulty pushing forward a resolution to both of these issues.

China has had to respond to more specific trade concerns raised by its trading partners. Before China's *Food Safety Law 2009*, pathogen limits in food were the main trade concerns raised by China's trading partners. For example, the United States raised concerns about the zero tolerance of pathogens in raw meat and poultry products.[2] China's WTO notifications became more transparent as procedures for formulation and revision of national food safety standards improved after the *Food Safety Law* came into force; however, trading partners continued to raise concerns. For example, after the national food safety standard for distilled liquor was released in 2009, Mexico raised a concern about the methanol limits. China received concerns from the EU that too many SPS notifications were made with short comment periods in June 2010. Bilateral negotiations during the SPS committee meeting between China and South Korea lasted for six years due to South Korea's concern that China's *Standards for Preserved Vegetables* might affect the export of its kimchi to China. Over the past couple of years China has attempted to address these concerns, with many of them being resolved.

26.2.4 Challenges for China in Accordance with WTO Rules

WTO/SPS notification and comment work currently faces challenges. Completing notification forms and handling comments requires significant resources each year. Personnel are unfamiliar with how to select forms, and limited facilities with English capabilities makes it difficult to complete the forms and respond to notifications. In responding to comments, China faces difficulties in determining the response time and mastering response skills.

Currently, about 40 comments are formally submitted to other WTO members through WTO/SPS national notification and enquiry points every year, but comments are not continuously tracked after submission. Therefore, further study on food safety regulations and technical standards of other members is needed. China is faced with the challenge of assessing the health, economic, and social impacts on China of the technical measures notified by other WTO members.

China's SPS work needs stronger participation by government agencies and industries. Almost all special trade concerns put forward by China in SPS regular meetings are prompted by obstacles encountered in foreign trade. China's lack of in-depth research capability on SPS measures notified by trade partners limits its ability to identify measures that exist as trade barriers. Bureaucratic divisions between China's food safety regulations/standards formulation and food safety supervision departments create gaps between promulgations of foreign technical regulations and assessment of the

---

[2] No. 251 Specific Trade Concern brought to SPS committee: Zero tolerance for pathogens on raw meat and poultry products.

policy impact of these policies. Furthermore, regulatory planning lacks participation by key stakeholders, especially food industry groups and companies.

China needs to expand its WTO/SPS expertise. SPS covers a wide range of professional disciplines, including food safety, animal and plant health, international trade, law, and economics. Professional expertise in these areas only began to develop after China joined the WTO. In 2005, the MOA and AQSIQ developed a database of SPS appraisal experts to engage in notification and comment. The NHFPC has accelerated technical research on national regulations and standards for food safety and formed a group of experts to help formulate national standards for food safety. Despite these efforts, China's expertise in the SPS field is still far behind that of developed countries, and research on the influence of foreign food safety regulations and standards on China's trade has yet to begin.

26.3 Case Study: China's Experience Regulating Beta Agonists at Home and at the Border

We use China's experience regulating beta agonists as a case study to explore the challenges regulators face as they oversee a food system modernizing rapidly and engaging with complex, dynamic international markets. The oldest and most common beta agonist is clenbuterol, a pharmaceutical first synthesized in the 1960s by a US company to treat bronchial asthma in humans. Now there are numerous related compounds, including salbutamol, ractopamine, and others, that are often referred to in China by their colloquial name, "shou rou jing."

Farmers in the United States and Europe began using clenbuterol as a feed additive during the 1980s when it was discovered that the compound also promotes efficient feed use and lean meat growth in livestock. However, clenbuterol can cause heart palpitations, shortness of breath, headaches, nausea, and vomiting in humans when consumed in food at high concentrations. In 1991, the United States Department of Agriculture (USDA) announced it would condemn meat products that contained clenbuterol [7], and Europe banned clenbuterol for livestock use in 1996, after a series of poisonings there.

Ractopamine hydrochloride was developed by a pharmaceutical company as a safer alternative to clenbuterol to promote weight gain and increase carcass leanness during the final stages of animal growth before slaughter. Ractopamine is more rapidly absorbed than clenbuterol and is excreted from the animal's body at a much quicker rate.[3] Furthermore, it is less likely to be activated in the animal's liver, and has lower risk for bioaccumulation [8].

26.3.1 Regulatory Challenges Introduced by Beta Agonists

Authorities in China have struggled to control the use of beta agonists in the domestic market since clenbuterol was first brought to China during the 1980s by a Chinese scholar who returned from the United States [9]. Clenbuterol became popular among

---

[3] A Chinese farmer told *Phoenix Magazine* that ractopamine cannot be detected by authorities if farmers stop feeding it to pigs a week before slaughter [9].

Chinese hog farmers and spread to fifty counties in eight provinces within a year. The muscular animals had a high proportion of lean meat and were called "bodybuilder pigs."

The first publicized Chinese clenbuterol poisoning incident occurred in Hong Kong in 1998, when 17 people fell ill after eating pig livers [10]. Since the first major incident in mainland China occurred in 2001 in Guangdong's Heyuan City, there have been at least 18 incidents of clenbuterol poisoning, including prominent cases in Shanghai and Guangzhou (see Table 26.1). At least one person has died and more than 1700 have fallen ill from ingesting clenbuterol [11]. The common practice of eating internal organs of pigs, where clenbuterol accumulates, has made Chinese consumers especially vulnerable to sickness.

China's MOA first prohibited the use of clenbuterol in animal feed and livestock production in 1997. A circular issued in 2000 by the MOA and the CFDA called for strict regulation and inspections of producers, manufacturers, and sales channels for

Table 26.1 Clenbuterol timeline in China.

Date	Incident
1964	Clenbuterol was invented in the United States to treat respiratory diseases [9].
1980s	A Chinese visiting scholar to America introduced clenbuterol to China. In one year, clenbuterol spread to fifty counties in eight provinces [9].
1997	MOA issued a document to prohibit the use of clenbuterol in animal feed and livestock production [12].
May 1998	Hong Kong, a number of people suffered clenbuterol food poisoning after consuming pig offal [10].
Nov. 2001	In Heyuan City, Guangdong Province, hundreds of people were treated for symptoms linked to clenbuterol [13].
Feb. 2002	All beta agonist use (including ractopamine) was banned [12].
May 2006	More than 100 employees in a plant in Dongguan, Guangdong province consumed pig lungs contaminated with clenbuterol [11].
Sept. 2006	336 people in Shanghai were hospitalized after eating pig meat or organs contaminated with clenbuterol [12].
Feb. 2009	Multiple incidents of clenbuterol poisoning occurred in Guangzhou causing sickness to 70 people [14].
Mar. 2011	CCTV television report uncovered how ractopamine and clenbuterol were being widely used in factory farms supplying Shuanghui in Henan province [15].
Mar. 2011	A meat processing plant in Conghua city, Guangdong Province, found 24 pigs containing clenbuterol [16].
Apr. 2011	Changsha, Hunan, 91 people were diagnosed with clenbuterol poisoning after attending a wedding [17].
Dec. 2011	China's ministry of industry and information technology banned production and sale of ractopamine [18].
Aug. 2013	Hungdao district, two people jailed after selling pigs found to contain clenbuterol [19].
Dec. 2013	Sanyuan, Shaanxi, two officers suspected of food regulatory malfeasance over clenbuterol [20].

clenbuterol, and proposed a testing plan. A 2002 “list of drugs forbidden for use in feed and animal drinking water” banned clenbuterol, ractopamine, and several other beta agonists. There were numerous testing and rectification programs aimed at producers, and feed and chemical manufacturers. Nevertheless, the use of clenbuterol and other beta agonists remained widespread among Chinese producers.

The attention on beta agonists peaked in 2011 when a CCTV exposé revealed the widespread use of clenbuterol by producers in Henan province who supplied hogs to a subsidiary of one of China’s largest meat companies. According to news media, the use of these substances was an open secret in the industry and it was reported that company demands for lean pigs encouraged the use of beta agonists. Media reports suggested that animal health certificates were routinely forged or purchased, and tests of hogs were evaded or defeated by subterfuge [21, 22]. While there were no reports of illnesses related to this incident, it heightened concerns among Chinese consumers about beta agonists [15]. Later in 2011 – a decade after the use of beta agonists in animal feed and livestock production had been banned – Chinese authorities banned production and sale of clenbuterol and ractopamine.

26.3.2 Beta Agonist Regulation and Trade

When China joined the WTO in 2001, it was a net exporter of pork and regulation of beta agonists was a domestic issue. Since then, China has become a significant importer of pork and two of its major pork suppliers – the United States and Canada – permit the use of ractopamine in pork production.

US authorities approved use of ractopamine in pork production in 1999 because it poses little or no risk to consumers when used properly. The feed additive has also been authorized for use in more than 20 other countries [23]. Nevertheless, China, the EU, Russia, and many other countries ban the use of ractopamine and its role in global meat trade has been controversial. In 2004, the Joint FAO/WHO Expert Committee on Food Additives (JECFA), a body of experts that provides scientific advice to Codex on veterinary drugs, recommended establishment of maximum residue levels (MRLs). Upon further review in 2010, the JECFA examined studies and recommended a ractopamine MRL for muscle, liver, kidneys, and fat. In 2012, the Codex Alimentarius Commission adopted MRLs for ractopamine in cattle and pig tissues. However, the EU, Norway, China, and other members expressed concerns over the decision. The EU – another major pork supplier to China – raised concerns over possible risks to humans and China raised concerns of ractopamine due to pig organs being consumed as a larger part of its traditional diet [24].

26.3.3 Imprecise Language and Misperceptions of Risk

Public alarm over poisonings resulting from consumers ingesting clenbuterol spilled over into food safety concerns on all products treated with beta agonists. Chinese officials and news media exaggerated the risk posed by imported pork by failing to distinguish between clenbuterol and ractopamine. In particular, imprecise language led to confusion. The Chinese chemical names for clenbuterol and ractopamine are phonetic translations of the English words that had no meaning to anyone except scientists, so the colloquial term “shou rou jing” was used to describe all beta agonists, even by officials and scientists. Official regulations list clenbuterol, ractopamine, and other beta agonists separately using their proper names, but in nearly all other discussions and media, beta agonists are referred to collectively as “lean meat powders.” Since clenbuterol was the most common beta agonist, “shou rou jing” became synonymous with “clenbuterol” in China. The distinction between clenbuterol and ractopamine was not well understood.

Only a few careful news media outlets properly distinguished between clenbuterol and ractopamine. For example, an article posted on a news site in Hangzhou in 2010 explained the difference between clenbuterol, ractopamine, and two other types of “lean meat powders” [25]. The Hangzhou article explained that ractopamine is less toxic than clenbuterol and included a table showing countries that banned ractopamine and acceptable tolerances in four countries and in the WHO and Codex Alimentarius. As the chemical terms become more familiar, news media appear to make the distinction more frequently. This linguistic precision is necessary for sound science, accurate risk assessment, and good regulatory policy.

The conflation of clenbuterol and ractopamine led to a presumption that both compounds are equally toxic. In view of the history of clenbuterol poisoning incidents in China, news media and consumers supported strict bans on imported pork from animals raised on ractopamine. This was expressed in China’s insistence on a zero tolerance for ractopamine in imported pork.

WTO trade rules are partly aimed at ensuring the even application of standards and regulations to prevent countries from using food safety and sanitary rules as barriers to imports. Beginning in the 1800s, trade in meat products between the United States and Europe was suppressed by use of disease and sanitation concerns as trade barriers [26], and similar disputes over hormones, pathogen reduction treatments, and beta agonists continue in the twenty-first century [27]. As China becomes increasingly dependent upon foreign sources for meat, Chinese consumers will benefit from unimpeded trade in those products.

26.3.4 Uneven Inspection of Foreign Meats

We analyzed data on the AQSIQ’s rejections of imported pork shipments to gain insight into the consistency and evenness of China’s regulatory policies on ractopamine. The AQSIQ reports monthly lists of rejected food shipments that show the product rejected, its source, importer, weight of shipment, and reason for rejection. We compiled the monthly reports from 2006 to 2014 and analyzed the number of rejected pork shipments. Nearly all of the pork shipments rejected were due to detection of ractopamine. For comparison, we also compiled data on monthly imports of pork derived from Chinese customs statistics.

Figure 26.1 presents the number of pork shipments rejected, as reported by the AQSIQ. Since 2006, the AQSIQ reported more than 365 rejections of pork shipments, the vast majority from the United States (Canadian pork products accounted for a few rejections). If inspections were carried out consistently, we would expect to find that the number of rejections varied in proportion to the volume of shipments reported by customs data. However, the timing of rejections does not correspond to the volume of trade. Rejections occurred intermittently, concentrated in certain time periods. There were long periods when no rejections occurred and there were several spikes in ractopamine rejections. The largest number of rejections occurred in 2007, but the number

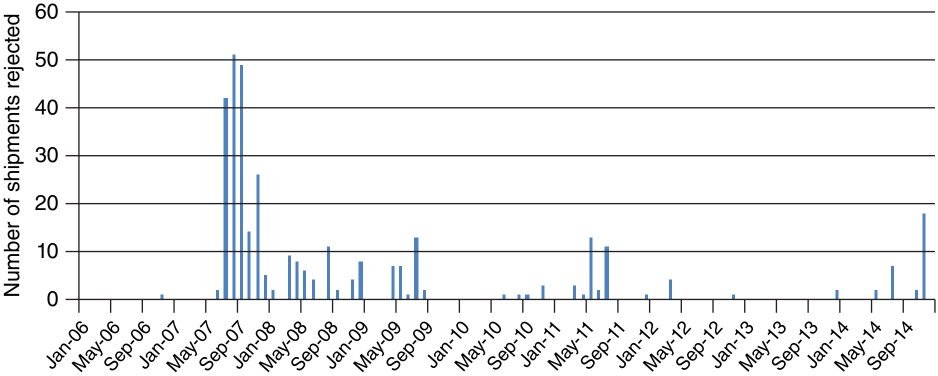


Figure 26.1 Ractopamine rejections by number of rejected shipments, 2006–2014. *Number of shipment rejected: Source: AQSIQ* [28].

decreased in 2008, even though the volume of imports increased dramatically. US news media suggested that the surge in pork rejections was linked to other trade disputes in 2007.[4] There were few rejections from 2010 to 2013, except for two months in 2011.

China and the United States have worked to implement measures to supply pork that satisfies Chinese requirements. China now requires that all US pork imports be accompanied by a certificate stating that the product is free from ractopamine residues. In 2014, China began requiring that all pork exports be certified by the USDA, either through a USDA ractopamine-free certification program or a screening program that includes mandatory residue tests. Nevertheless, another surge in rejections occurred late in 2014, and China banned US facilities that produced the rejected products. This appears to be a move toward stricter, more standardized screening for ractopamine in imported pork. While this ban has since been lifted,[5] uncertainty about the application of standards at the border may increase the risk involved with trade and deter pork importer and exporters.

26.3.5 Economic Implications of China's Ractopamine Regulations on Trade

Large, vertically integrated producers may find it feasible to build ractopamine-free facilities if they have a steady source of demand. In fact, volumes shipped to China vary with market conditions. Thus, a facility dedicated to supplying China is likely to be underutilized during periods of slow demand. Most producers in the United States have a strong incentive to use ractopamine since the efficiency in weight gain and lower feed costs increases profit by an estimated $5 to $6 per hog [31]. Moreover, exporters seldom ship entire carcasses to China. Pork shipments to China are typically composed of organs, tails, feet, or specific cuts of meat procured by dealers from multiple suppliers. Other parts of the animal are sold in the US market or to other countries. The flexibility

---

[4] The spike in rejections was viewed by some as retaliation against US curbs on imports of Chinese seafood over food safety concerns [29]. Pork rejections in 2009 coincided with depressed prices in the Chinese pork market and punitive sanctions on Chinese tire imports.

[5] China reinstated 14 US pork processing and cold storage facilities in late 2015 [30].

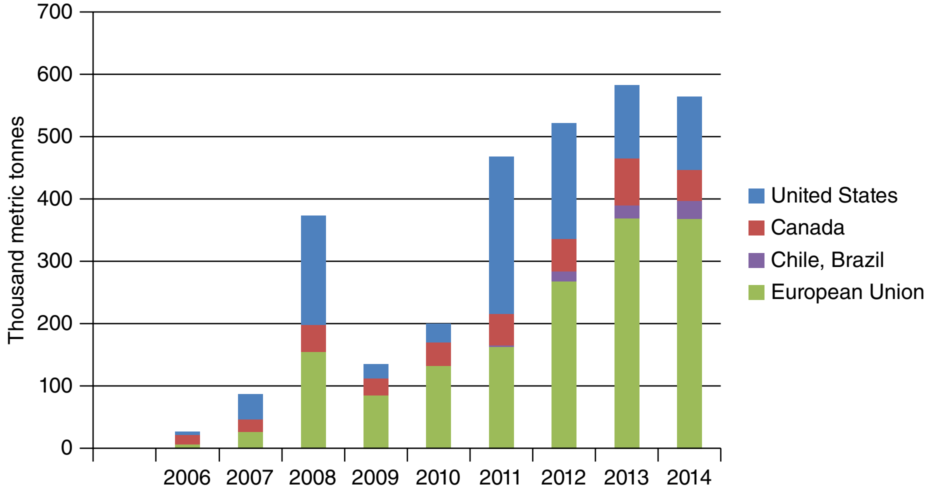


Figure 26.2 China pork imports, by supplying country.
*Note: Data for Harmonized System code 0203***.** *Source: China customs statistics accessed in Global Trade Information Services, Global Trade Atlas* [32].

built into pork supply chains increases the likelihood that pork raised ractopamine-free may be co-mingled with meat containing ractopamine residues when shipped to China.

China produces nearly half of the world's pork, and as output grows it is placing strains on domestic feed supplies and natural resources. The rising opportunity cost of labor and more stringent environmental regulations for livestock farms limit the expansion of domestic supplies and raise production costs. China's imports of pork first surged in 2008 after a disease epidemic resulted in short domestic supplies and soaring prices in 2007 (see Figure 26.2). At that time, the United States and Canada – both of which permitted use of ractopamine – supplied most of China's imports.

Given its limited land and water resources and increasing attention to environmental protection, China's rising consumption of meat will strain its domestic production capacity. Projections to 2024 by the USDA and the Chinese Ministry of Agriculture anticipate an increase in net imports of pork during 2015–2024 (see Figure 26.3). The increase is especially striking in view of China's status as a net exporter of pork until 2005. While China has increased imports from European countries that do not use ractopamine, this has been facilitated by a diversion of pork from Russia due to a politically motivated ban on European and US agricultural imports. Limited feed resources and strict environmental and animal welfare standards in Europe are likely to raise the long-term cost of pork sourced there. It will be in China's long-term interest to develop reliable, but flexible pork supplies from the United States.

26.4 Conclusion

This chapter has highlighted the progress China has made in overhauling its regulatory regime for food safety, and the challenges it faces as it engages with global agricultural markets. As China's demand for meat exceeds its production capacity, harmonization

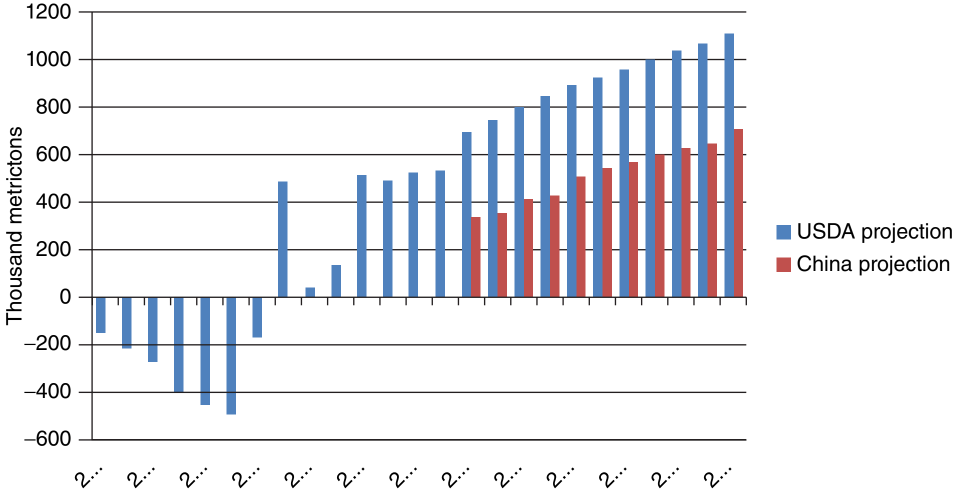


Figure 26.3 China net imports of pork, projected to 2024.
Net imports = imports – exports. Data for 2015-2024 are projections. Source: USDA baseline projections [33]*; Ministry of Agriculture* (*China*) *Market Early Warning Expert Committee* [34].

with global standards and greater transparency benefits Chinese consumers and creates commercial opportunities.

An effective food safety system needs to be staffed with personnel knowledgeable about both technical matters and the operation of markets. Food safety regulators need to simultaneously assess potential risks to consumers posed by products supplied by both domestic and international markets. There is a need for objective, precise, risk analysis that focuses on protecting consumers rather than protecting commercial interests. Regulators need to be aware of the need for flexibility in supply chains to achieve efficiency in volatile markets. Dedicated supply chains that segregate products from hog production to processing and distribution, while maintaining traceability may sacrifice flexibility and efficiency. As China carries on with its rapid pace of development and integration with global markets, food safety and international trade issues will continue to collide and present new challenges for regulators.

References

1 World Trade Organization (WTO). (1995) *The WTO Agreement on the Application of Sanitary and Phytosanitary Measures (SPS Agreement).* https://www.wto.org/english/tratop_e/sps_e/spsagr_e.htm (accessed November 2016).

2 World Trade Organization (WTO). (1995) SPS Information Management System. http://spsims.wto.org/ (accessed November 2016).

3 Ministry of Health. *Management of National Food Safety Standards.* No.77 Decree of Ministry of Health. http://www.moh.gov.cn/mohzcfgs/pgz/201011/49540.shtml (accessed November 2016) [in Chinese].

4 WTO/TBT-SPS Notification and Enquiry of China. (2015) *WTO/TBT-SPS Notification.* http://www.tbt-sps.gov.cn/tbtTbcx/getList.action (accessed November 2016) [in Chinese].

5 China General Administration of Quality Supervision, Inspection and Quarantine (AQSIQ). (2014) *Annual Report of Technical Trade Measures of China Complied.* China Zhijian Publishing House [in Chinese].

6 World Trade Organization (WTO). (2015) Specific Trade Concerns 1995–2014 report and corrigendum. https://www.wto.org/english/tratop_e/sps_e/sps_e.htm (accessed November 2016).

7 Food Safety and Inspection Service (FSIS). (1995) *Clenbuterol.* http://www.fsis.usda.gov/Oa/background/clenbute.htm?redirecthttp=true. (accessed May 2015).

8 Alemanno, A. and G. Capodieci. (2012) Testing the limits of global food governance: the case of ractopamine. *European Journal of Risk Regulation* 3.

9 Phoenix Magazine. (2011) From 8.5 Program to Toxic Additive: The History of Clenbuterol. http://3y.uu456.com/bp_6lmjw2xnxk01k8300sra_1.html (accessed January 2014) [in Chinese].

10 Sit, T. and G. Tam. (2003) Control on the Illegal Use of Clenbuterol in Pigs in Hong Kong. Fifth International Symposium on the Epidemiology and Control of Foodborne Pathogens in Pork. http://lib.dr.iastate.edu/safepork/2003/allpapers/89/ (accessed November 2016).

11 Zhou, G., W. Zhang, and X. Xu. (2012) China's meat industry revolution: Challenges and opportunities for the future. *Meat Science* 92(3), 188–196 [in Chinese].

12 Gu, Z. and L. Zheng. (2007) Lessons from Outbreak Of Food Poisoning Caused By Clenbuterol in Shanghai in Sept. 2006. *Chinese Journal of Food Hygiene*: 01 [in Chinese].

13 People.com.cn. (2002) Guangdong Heyuan 'Poison Pork' Pork Poisoning Incident, June 21 [in Chinese]. http://people.com.cn/GB/shehui/212/6848/index.html (accessed November 2016).

14 Food Poison Journal. (2009) 70 Ill after Eating Steroid Tainted Pork in China. http://www.foodpoisonjournal.com/foodborne-illness-outbreaks/70-ill-after-eating-steriod-tainted-pork-in-china/#.VXcG209VhBe (accessed November 2016).

15 Chen, M. and G. He. (2012) Chinese food safety: a case study of pig-raising industry. *Management Science and Engineering* 6(2), 107–110.

16 Food Safety Net. (2011) Guangzhou Continues Battle with use of drugs in pig. http://foodsafety.suencs.com/archives/tag/clenbuterol/page/5 (accessed November 2016).

17 Zhou, W. (2011) China Daily. Tainted Food sends more than 300 to hospitals. April 25, 2011. http://www.chinadaily.com.cn/china/2011-04/25/content_12383756.htm (accessed November 2016).

18 Xinhua. (2011) China bans production, sale of ractopamine. December 23, 2011. http://news.xinhuanet.com/english/china/2011-12/23/c_131323957.htm (accessed November 2016).

19 Peninsula Metropolitan News. (2014) Two jailed after knowingly selling pork with 'lean meat powder'. May 5. http://news.bandao.cn/news_html/201405/20140505/news_20140505_2406545.shtml (accessed November 2016) [in Chinese].

20 Ma Zhifeng. (2014) Two officers in Shaanxi Sanyuan County suspected of neglecting food supervision duties as pork containing "shou rou jing" enters the market, Sept. 11. http://www.chinanews.com/fz/2014/09-11/6581291.shtml (accessed November 2016) [in Chinese].

21 Wang, P. (2011) *Weekly quality report.* Beijing: China Central Television. March 15, 2011 [in Chinese].

22 He, J. (2001) "Truth about 'body builder' pigs revealed." Show Shanti. March 22, 2011 http://showshanti.com/shouroujing-clenbuterol-healthy-and-beautiful-pigs-revealed/ (accessed January 2014) [in Chinese].

23 Food and Agriculture Organization of the United Nations (FAO) (2012). Information sheet – Discussion on ractopamine in codex and in the Joint FAO/WHO Expert Committee on Food Additives (JECFA). FAO, Rome, Italy, 26 April 2012. http://www.fao.org/fileadmin/user_upload/agns/pdf/Ractopamine_info_sheet_Codex-JECFA_rev_26April2012__2_.pdf (accessed November 2016).

24 Centner, T. J., J. C. Alvey, and A. M. Stelzleni. (2014) Beta agonists in livestock feed: Status, health concerns, and international trade. *Journal of Animal Science*, 92(9), 4234–4240.

25 Dahangzhou (2009). What is "Shou rou jing" and the regulations on use, September 9. http://news.dahangzhou.com/210436.html (accessed November 2016) [in Chinese].

26 Olmstead, A. L. and P. W. Rhode. (2015) *Arresting Contagion: Science, Policy, and Conflicts over Animal Disease Control.* Cambridge: Harvard University Press.

27 Arita, S., J. Beckman, L. Kuberka, and A. Melton. (2014) *Sanitary and Phytosanitary Measures and Tariff-Rate Quotas for U.S. Meat Exports to the European Union.* ERS Special Outlook. (LDPM-245-01) 25 pp, December.

28 China General Administration of Quality Supervision, Inspection and Quarantine (AQSIQ). (2015) Import and export food risk warning. http://www.aqsiq.gov.cn/ztlm/jckspfxyj/ (accessed November 2016).

29 Inside U.S. Trade. 2007. Industry Sees Retaliation in Chinese Ban On U.S. Meat Shipments. June 20, 2007.

30 Singh, S. 2015. China to Lift Restrictions on U.S. Pork-Processing Plants. Bloomberg Business. Oct 22, 2015. http://www.bloomberg.com/news/articles/2015-10-22/china-agrees-to-lift-restrictions-on-u-s-pork-processing-plants (accessed November 2016).

31 Stuart, B. 2013. Math puts ractopamine economics in perspective. Feedstuffs Foodlink, Miller Publishing Co, 2 April 2013. http://feedstuffsfoodlink.com/blogs-math-puts-ractopamine-economicsperspective-6978 (accessed November 2016).

32 Global Trade Information Services. (2015) *Global Trade Atlas.* Columbia, South Carolina.

33 U.S. Department of Agriculture, Office of the Chief Economist. February 2015. USDA Agricultural Projections to 2024, Long-term Projections Report OCE-2015-1.

34 Ministry of Agriculture (China). (2015) *China Agricultural Outlook 2015-2024: Market Early Warning Expert Committee.* China Agricultural Science and Technology Press (CASTP): Beijing [in Chinese].

Part 6

Commodities

27

Meat Safety in China

Guanghong Zhou, Keping Ye and Ronald Keith Tume

Nanjing Agricultural University, Nanjing, China

27.1 Introduction

27.1.1 The Present Status of China's Development of the Meat Industry

During the last 30 years, China has gone through rapid economic development as a result of industrialization and modernization, together with an increasing population and improved food supply. Since the 1990s, the meat industry in China has undergone major changes, leading to the accelerated growth in sales of fresh meat, and also the development of chilled and processed meat products, a sector that has experienced a major transition. During this development period, some state-owned meat operations were integrated with fast-growing private sector processing enterprises. Today, China has become the largest meat-producing country in the world. Over the last 30 years, the total production of raw meat has been consistently increasing at an annual average rate of 5.8% per annum [1]. In 2014, the total meat production in China was 87.07 million tons (Mt.) (Figure 27.1), including 56.71 Mt. of pork, 6.89 Mt. of beef and 4.28 Mt. of sheep meat (Data derived from National Bureau of Statistics of China) [2].

27.1.2 The Importance of Meat Safety

The rapidly growing Chinese economy has led to a gradual change in focus in the meat industry. Previously the focus was essentially the provision of fresh meat, largely for daily consumption, whereas now there is a large emphasis on a range of chilled meat products, together with the development of processed meat products, such as cooked meat products, Chinese traditional meat products and prepared meat products, and awareness of meat safety and quality issues has increased. Meat products, because of their rich nutrient content, together with their desirable flavor, have an important position in overall food consumption. However, unless the meat is processed correctly and then properly handled during storage and transport, it can readily become unacceptable for human consumption because of spoilage. In recent years, meat safety has been a prominent issue across China because of societal concerns. The broad view of meat safety is that meat and meat products should not contain any components that may harm human health. Consumption of meat must not lead to acute or chronic poisoning, infection with pathogenic bacteria or

Food Safety in China: Science, Technology, Management and Regulation, First Edition.
Edited by Joseph J. Jen and Junshi Chen.

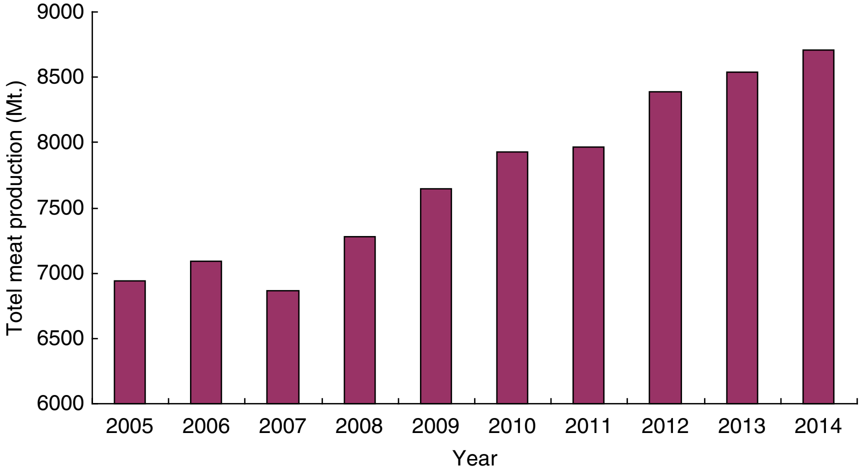


Figure 27.1 The total meat production in China for each year of the last decade (*Source:* Data derived from National Bureau of Statistics of China)[2].

viruses, or in any way harm the health of consumers or their offspring [3]. Factors associated with meat safety involve the whole of the production chain, covering animal production, complex processing, chilling/freezing and transport, right through to the retail level and consumption. Each step must involve a complete understanding of food safety principles, together with appropriate supervision and management, so that at any step the overall safety of the meat product will not be adversely affected.

In recent years, awareness of meat safety incidents in China has become more apparent and has been widely publicized. Incidents associated with meat safety in China have been reported at all of the steps in the meat chain, including residues from veterinary pharmaceuticals during the animal breeding/production process, indiscriminate slaughter and deliberate adulteration for financial gain [4]. These incidents became the focus of government and of public concern, which seriously damaged consumers' confidence and trust in meat safety. Other incidents have included food-borne pathogens, veterinary pharmaceutical residues including antibiotics, heavy metals and other hazardous substances. In recent years, some of China's exported meat has been rejected and returned by the importing country because of such issues. This has affected the image of Chinese products in the international market, which has ultimately affected the sustainable development of China's meat and other new food industries.

In this chapter, we have attempted to make comparisons, where possible, between the Chinese regulations and procedures relating to meat safety issues and those from the well-established meat industries in the United States, Europe and Australia, all these being major exporters of meat with a high reputation for safety and quality.

27.2 Hazards Associated with Meat Safety in China

Meat can readily become contaminated with foreign materials (chemical, physical and biological), which may affect human health if ingested. Generally, the origin of meat safety problems can be divided into one of three stages in the entire meat chain. The first is during the animal breeding/production process, where there may have been an inappropriate use of feedstuffs or feed additives, or the use of veterinary pharmaceuticals, leading to the presence of hormone residues, heavy metals and pesticide residues in the food chain, and therefore potentially impacting on human health. The second stage is during slaughter and processing, where physical and chemical contamination has occurred. There is also the possibility of harmful microbial contamination of the meat surfaces resulting from transfer from the hide or skin, which necessitates optimal decontamination and chilling/freezing procedures. The final stage is the distribution chain, including packaging, storage, transportation and sales, where management of the cold chain is imperative. The control of biological hazards, such as spoilage and pathogenic bacteria, viruses and parasites is also particularly important at this stage, where any inappropriate practices will impact on meat safety.

27.2.1 Chemical Contamination

Chemical contamination of meat originates from various sources and may have harmful effects for human health [5]. There are four major categories of potential chemical contaminants in foods of animal origin, as presented below.

27.2.1.1 Residues from Veterinary Pharmaceuticals

Veterinary pharmaceuticals are generally used in farm animals for therapeutic and prophylactic purposes, and include antibiotics, hormones, and antibacterial and antiparasitic agents [6]. The inappropriate use of excessive amounts of antibiotics has been a serious issue in China, as a result of their accumulation in the animal and in meat. Not only can their excessive use introduce problems for farm animal welfare, but residual amounts of these antibiotics, or their metabolites, in meat and other derived foods, may be harmful to human health. Antibiotic residues can cause acute or chronic toxic effects and bacterial resistance to antibiotics. Although China has set standards such as Limits for Veterinary Drug Residues in Animal Food and Standards for Additive Drugs in Fodder [7], the problem of veterinary pharmaceutical residues still remains serious. The reasons for the presence of antibiotic residues in meat mainly include the illegal use of veterinary medications, the irrational use of veterinary pharmaceuticals and violation of the regulations regarding drug-withdrawal times prior to slaughter [8]. This has become an increasingly serious problem because of their potentially harmful effects on human health.

The following incidents are cited as examples of some food safety problems in China. Ractopamine, a β-adrenoceptor agonist, when used in high doses in feed, promotes weight gain in pigs, reduces fat deposition and increases lean meat yield. As found with other β-agonists, this can cause a reduction in eating quality, particularly tenderness and juiciness. However, the commercial benefits of adding ractopamine to feeds has been seen by some producers to outweigh any harmful side-effects that may arise in humans from consumption of meat containing its residues. In China in 2001, ractopamine was reported to be responsible for an outbreak of food poisoning and subsequently, in 2002, was prohibited for use in animal feed and water, together with all other β-adrenergic agonists [9]. However, later in 2002 in Henan province, the use of ractopamine in pig rearing was again detected and the government immediately launched an extensive investigation to restrict the use of ractopamine in animal feed [10]. However, on 6 July 2012, the international reference standard Codex Alimentarius Commission narrowly approved the adoption of a maximum residue limit (MRL) of 10 parts per billion (ppb) for muscle cuts of beef and pork [11].

Although the Australian government body, the Australian Pesticides and Veterinary Medicines Authority (APVMA) approved the use of strictly regulated amounts of ractopamine in 2003 [12], it has only been used by the pig industry and, to our knowledge, has not been introduced or used within the beef industry. Its use in the US and Canada has significantly curtailed their pork exports to China in recent years. In 2014, a number of US plants were disqualified from exporting to China because of ractopamine-residue violations [13].

In Australia, the APVMA regularly updates lists of registered veterinary products for use in cattle, sheep and pigs, specifying their withholding periods (WHPs) and export slaughter intervals (ESIs) [14, 15] For veterinary antibiotics, only Australia and the United States have strict procedures for their registration, requiring the evaluation of their antibiotic resistance. Antibiotics such as fluoroquinolones, cephalosporins, gentamycin and others are essentially prohibited for use in food-producing animals.

The use of hormone growth promotants (HGPs) in beef has been banned in China and any meat imports must be free of the synthetic form or physiological amounts of the natural oestradiol. Although some countries, including within the EU, have stopped the use of these compounds, others, including the the US, Canada, Japan, New Zealand and Australia have approved their use at specified levels. In Australia, only about 40% of cattle are given this hormone and any beef for export to China and other countries must provide a national vendor declaration (NVD) to the National Residue Survey (NRS) to screen residues [16].

27.2.1.2 Additives Used in Meat Processing

Food additives have played, and continue to play, an important role in the development of products for the meat processing industry, both for preservation by pickling and/or salting, or by enhancing the functionality of muscle protein· [17] However, the uncontrolled use of non-approved food additives may do harm to both meat quality and safety attributes, possibly causing acute and/or chronic hazards to consumers.

Although these approved food additives are used to improve meat quality and safety, their excessive use can have harmful effects on human health. For example, the addition of polyphosphates has been important for improving meat quality and the functionality of processed meat products. However, where there is a dietary intake of excessive amounts of polyphosphates, the absorption of calcium is reduced in humans, causing the loss of calcium from bone tissue [18]. For this reason, the China National Standard GB 2760-2011 has imposed a maximum dosage of 5 g/kg in food products [19].

The additions of nitrite and/or nitrosamines are known to improve meat color and to extend shelf-life [20], as used for smoked meat products and fermented sausage. Under acid conditions, nitrite produces ionized nitrite, which then combines with myoglobin in meat, generating nitroso-myoglobin and giving the meat a bright red appearance [21]. However, nitrite is sometimes used by the medical profession to treat specific diseases. At low concentrations, nitrite has been shown to reduce the oxidation of fat and protein, leading to an inhibition of the proliferation of colon cancer cells. [20]. However, high concentrations of nitrite can promote the proliferation of cancer cells [22]. In order to maximize the color effects in meat products, and therefore gain additional financial benefit, some unscrupulous processors have used excessive amounts of the relatively inexpensive nitrite in their products, potentially risking human health. According to the China National Standard GB 2760-2011, the dosage of nitrite should be less than 5 g/kg in meat products; the maximum residue limits should be 5 mg/kg.

In China, a number of non-compliant food additives have been used for financial benefit without any consideration of the associated health risks to humans. One such example is Sudan Red, an illegal food additive, which has been used widely for the coloration of meat products to improve their appeal. Sudan Red is an organic compound, typically classified as an azo dye and is classified as a category 3 carcinogen by the International Agency for Research on Cancer [23].

27.2.1.3 Formation of Pollutants During the Manufacture of Processed Meats

Depending on the product, harmful compounds can be generated during processed meat manufacture. In China, processed meat products are often smoked or preserved for the purposes of improving their sensory characteristics, microbiological condition, and their shelf life. During these procedures, not only are sensorially beneficial and preservative components formed, but there can be generation of carcinogenic compounds such as polycyclic aromatic hydrocarbons (PAHs), heterocyclic amines (HCAs) and acrylamide [20]. Critically, these compounds have been identified as carcinogenic and mutagenic and are considered as pollutants of concern based on the potency of their potentially adverse effects on health.

Polycyclic aromatic hydrocarbons. PAHs (e.g. benzopyrene) are compounds readily produced when insufficient oxygen or other factors result in incomplete combustion of organic matter. As a consequence, PAHs can be present in smoked meat products [24].

Heterocyclic amines. HCAs are a group of chemical compounds, many of which are formed during cooking. Epidemiological studies have shown associations between intake of HCAs and some cancers. Cooking meat at high temperatures over an open grill may lead to the greater formation of such compounds, which originate from polyunsaturated fatty acids [25].

Acrylamide. Acrylamide is considered a potential occupational carcinogen by US government agencies and is classified as a Group 2A carcinogen by the World Health Organization (WHO) International Agency for Research on Cancer (IARC) . It can be generated in meat products during high-temperature cooking [26], and so can be produced in fried meat products. Many feeding trials with animals have shown that ingestion of acrylamide results in neurotoxicity, infertility, gene mutation and carcinogenicity [27].

Recently, the IARC listed processed meats as Group I carcinogens and fresh red meats as Group IIA carcinogens. This was based on findings which indicated that processed meats contain PAHs, HCAs and acrylamide as a result of processing. However, for the recommended dietary intake level of processed meats, the amounts of these compounds are far below the minimum concentrations that have been suggested as being carcinogenic in humans [22].

27.2.1.4 Environment Pollutants

In keeping with the rapid growth of the Chinese national economy, there has been a huge growth in the amounts of resources used, with a concomitant amount of waste materials generated (waste water, waste gas and waste residues). When discharged, they cause pollution of the natural environment such as soil, water and air [28]. Where the environment does contain polluted materials, there is clearly a problem for the safe production of livestock, together with concerns for the integrity and safety of the meat and products [29]. Most of the environmental pollutants originate as waste by-products from various industrial processes involving combustion. Many environmental pollutants have high chemical stabilities and therefore remain in the environment for many years, ultimately bio-accumulating in various tissues of aquatic and livestock animals, according to their hydrophilic or lipophilic properties.

27.2.1.5 Heavy Metals

With increasing industrial development, heavy metal pollutants originating from various industrial production processes are finding their way into the animal bio-systems of land, water and air. Through feeds, feed additives and drinking water, metals such as cadmium, lead, mercury and thallium can accumulate in various tissues, including muscle, liver and kidney. The presence of high concentrations of heavy metals in meats has the potential to cause harmful effects in consumers, such as disruption of various metabolic processes and disorders of the gastrointestinal, urinary and nervous systems [30]. In 2007, the Shenzhen Industry and Commerce Bureau tested 247 batches of meat products and the results showed that 10 batches of pork meat products exceeded the standard limitation for heavy metals [31]. Therefore, the pollution of heavy metals in meats must not be ignored [32], with ongoing testing being required. Australia uses the European Commission Regulations (Nos. 1881/2006 and 629/2008) for the heavy metals mercury, lead, cadmium and tin.

27.2.2 Biological Contamination

Biological contamination is always present on the external surfaces (hides and skins) and in the gastrointestinal tracts of animals entering slaughter facilities. Sporadically, contaminants are found at low levels in organ tissues such as lymph nodes [33]. Therefore, carcasses are very susceptible to contamination during slaughter and dressing when the hide is removed and the underlying tissues become exposed to the environment. To minimize the risk of carcass contamination from the animal, the industry in China has introduced a number of effective intervention strategies, as discussed later. Since food safety has become such an important concern for public wellbeing, the authority responsible is presently establishing a number of web-based databases such as those of the Chinese Center for Disease Control and Prevention, the National Health and Family Planning Commission of the People's Republic of China and the Data Center of China Public Health Science. Also, a web-based statistical analysis of recently collected data on food-borne diseases has been initiated, but unfortunately does not include historical data.

27.2.2.1 Bacteria

Microbial contamination is readily introduced from the environment, sometimes at high levels, and may include both spoilage organisms and pathogens. A major pathway for microbial contamination originates from the hide and skin, where microorganisms are transferred between the animals on-farm as well as during transport and lairage. Of major concern is the potential transfer of pathogenic *Salmonella* and *Escherichia coli* (O157: H7) from fecal-contaminated hides [34]. In many countries, including China, a number of interventions have been introduced to minimize carcass contamination. Hide washing and de-hairing procedures on "dirty" cattle when leaving the farm or feedlot have been shown to be effective in reducing contamination. At slaughter, regulatory procedures for carcass dressing and processing have been introduced to minimize the transfer of microorganisms between hides and also from the gastrointestinal tract contents to the carcass and meat surfaces [35]. These include specified handling procedures, the use of hot water sterilization of knives and equipment, and the sanitation of stainless steel surfaces. Many slaughterhouses have set up effective washing procedures prior to carcass entry into the chiller and these mainly are based on hot water (75–90 °C, 15 s) spraying while others use organic acids at USDA and EU approved levels.

The microorganisms commonly found on meat and meat products are shown in Table 27.1.

The loss of meat quality at the commercial, and particularly the retail level, mainly results from spoilage-causing microorganisms, thus leading to reduced food supplies and economic losses through the shortening of shelf life. During their growth, spoilage bacteria hydrolyze meat proteins and lipids, producing various substances such as aldehydes, ketones and alcohols by enzymatic catabolism [36], many of which result in undesirable flavors. Microorganisms, such as micrococci and Gram-negative rods, have been the main focus since they are mainly responsible for spoilage and the loss of acceptable eating quality in meat products. They include *Pseudomonas*, *Shewanella putrefaciens*, *Photobacterium phosphereum*, *Brochothrix thermosphacta* and the cold-tolerant Enterobacteriaceae, *Acinetobacter* spp., *Alcaligenes* spp., *Moraxella* spp., *Flavobacterium* spp., *Staphylococcus* spp., *Micrococcus* spp., coryneforms, fecal streptococci and lactic acid bacteria (LAB) [37].

Microbial pathogens can cause mild, severe, acute or chronic illness, or even death in humans. The main pathogens sometimes found in meat include *Listeria monocytogenes*, *Salmonella* spp., *E. coli* O157: H7 and *Staphylococcus aureaus* [38, 39]. In the past ten years, fewer than 20,000 major food poisoning incidents per annum have been officially reported in China. In 2012, 6685 incidents were reported, with 56.1% being attributed to microorganisms [40]. The Chinese government set China National Standard GB29921-2013 for limits

Table 27.1 Genera of bacteria most frequently found on meat and meat products.

Microorganism	The most frequently found bacteria in meat products
Spoilage bacteria	*Acinetobacter, Alteromonas, Arthrobacter, Bacillus, Brochothrix, Carnobacterium, Corynebacterium, Cronobacter, Lactobacillus, Leuconostoc, Micrococcus, Pseudomonas, Serratia, Streptococcus, Weisella.*
Pathogens	*Aeromonas, Brucella, Salmonella, Campylobacter, Listeria, Streptococcus, Bacillus, Clostridium, Escherichia, Enterobacter, Helicobacter, Mycobacterium, Plesiomonas, Shigella.*

of *Salmonella*, *L. monocytogenes*, *E. coli* O157: H7, *S. aureus* and *Vibrio parahemolyticus* [41]. In Australia, no limits are specified for *Listeria* numbers in fresh meats, given that the meat will be cooked. Similarly, for most uncooked processed products, where there is reliance on pH and water activity to restrict growth.

According to the CFSA (China National Center for Food Safety Risk Assessment), for the period from 1964 to 2010, the number of reported food related incidents of listeriosis was 147, including one incident involving 82 patients. The mortality rate for the clinical cases was about 26% (34/130). This outbreak was widespread, with 28 provinces involved, among which Sichuan, Jiangsu, Guangdong, Beijing and Shanghai were most affected. However, the food type responsible for this incident was not identified.

E. coli O157 is the most common member of a group of pathogenic *E. coli* strains producing verocyto toxin and Shiga toxin [42]. The first outbreak of *E. coli* O157: H7 in China was in 1999 in Xuzhou, Jiangsu Province, in which 131 cases were reported, with only 16 responding to treatment [43]. Again, the food type responsible for this outbreak was not identified.

27.2.2.2 Viruses

Viral agents, including norovirus, hepatitis A, enteroviruses and avian influenza, are the cause of the highest number of cases of mild food-borne gastroenteritis. Transmission is mainly associated with poor sanitation, inadequate cooking or cross-contamination before meat consumption. Viruses are unable to grow in foods and are generally sensitive to cooking. Their control in ready-to-eat foods should be managed through training of food service workers with the appropriate skills in sanitation and in hygienic practices. Norovirus is very contagious and can be transferred directly from an infected person, from contaminated food or water, or by touching contaminated surfaces. The ability of this virus to survive in extreme environments is robust and so it can be a problem throughout all climatic conditions throughout the year. Since 2013, awareness of norovirus has become more prevalent, with a major outbreak occurring during the winter of 2014. Between January and November in 2015, the number of people affected by norovirus totaled 88 (Chinese Center for Disease Control and Prevention). However, once again, the food type responsible was not identified.

Avian influenza has a high virulence for birds and is highly pathogenic, resulting in almost a 100% death rate in birds. It was initially believed that the avian influenza virus did not infect humans. However, recent reports in China have shown that avian influenza can cause human infections. In 1997 in Hong Kong, H5N1 was first reported to be transmitted to humans [44]. Up to July in 2013, China had 133 patients affected by H7N9, of which 44 died. Four provinces in the east of China were mainly affected and included Jiangsu, Shanghai, Zhejiang and Anhui (data from National Health and Family Planning Commission of the People's Republic of China, 9 August 2013). However, there is still no evidence that avian influenza can be transmitted to humans. To handle the avian influenza problem, China has introduced strict controls for live poultry markets. In Nanjing, Shanghai and other cities in the east, since the epidemic in 2013, the authority has banned all live poultry trading. However, avian influenza has not been eradicated in China. Between September 2014 and February 2015, four different types of avian influenza virus were reported in various incidents. These included 28 cases of infection with H5N2, 2 with H5N8, 1 with H5N3 and 19 with H5N1 (Data from General Administration of Quality Supervision, Inspection and Quarantine of People's Republic of China). In 2015, according to the National Health and Family Planning Commission of the People's Republic of China, 132 cases of avian influenza infection were reported, which resulted in the deaths of 65 people.

27.2.2.3 Parasites

Illnesses caused by parasites have increased in recent years, with the involvement of parasites such as *Clonorchis sinensis*, mouth nematode, *Paragonimus westermani*, *Angiostrongylus cantonensis* and cysticercus. These parasites use domestic animals as their hosts. Consequently, if raw meat is not well cooked then it may be contaminated by parasites and consumption of such meat may lead to infection. The parasites that can be transmitted by pork include *Taenia solium*, *Trichinella spiralis*, *Sarcocystis suihominis* and *Toxoplasma gondii*, causing taeniasis, trichinosis, sarcocystosis and toxoplasmosis. Beef can be the source of tapeworms (*Taenia saginata* cysticercus) and *Sarcocystis hominis*, and through feces-contaminated water, may serve as an indirect vector for transmission of *Giardia duodenalis* (or *lamblia*) and *Cryptosporidium parvum*. Meat from poultry (mainly when raised outdoors), can transmit *Cryptosporidium* and *Toxoplasma gondii*. *Trichinella* can also be transmitted through meat [33]. To date, there have been about 31 million patients affected with filariasis in China (data from CDC database).

27.2.3 Physical Contamination

Physical contamination of meat and meat products can occur at any stage of the overall process, from animal production, through transport and the processing and distribution chains. Physical hazards can be divided into two categories: (i) accidentally caused by the presence of physical foreign bodies including bone chips, metal, glass, wood, plastic, stones; (ii) adulteration caused by contrived factors, such as water-infused meat and meat substitution; (iii) use of unsuitable, poor-quality packaging materials, such as plastic packaging materials that contain non-polymerized free monomers [45]. Such packaging materials are not fit for food use and may directly affect the health of consumers.

During animal production, there is an opportunity for animals to consume small amounts of oxides of lead, zinc, cadmium and antimony originating from feed supplements present in ceramic and enamel containers. When consumed, these metals remain in meat products [46]. In the processing/packing area, where meat surfaces may be exposed to plastic packaging materials containing non-polymerized free monomers, the residues of the chemical treatment agents, and their low molecular weight cleavage products, may be transferred to meat [47]. Moreover, if the meat comes into contact with various inks containing polychlorinated biphenyl, benzene, toluene, xylene or other toxic carcinogenic substances from waste packaging materials, then harm could be caused to consumers [48].

Adulteration of food refers to the substitution of a quality food material with a low-cost material possessing similar physical properties, but of lesser quality, for the deception of the purchaser and hence greater profits for the offender. In recent years, such adulteration and fraud techniques have been evident in China, where a premium-quality meat has been replaced with a cheaper meat, or alternatively with water-infusion, thus significantly reducing the product cost [49].

In China, a meat product termed "beef extract" is used widely as an edible essence for the enhancement of flavor in various beef products. The main components of these extracts are creatine, polypeptides, amino acids, nucleotides, organic acids, minerals and various vitamins. Provided the extract is used in strict accordance with the relevant standards, such as the China National Food Safety Standard for Using Food Additives [19], when eaten in moderation, these products are harmless to human health. However, there is evidence that some companies in China have, until recently, added beef extracts to lower-value meat products such as pork and poultry, and then selling the products as beef, thereby reaping huge profits based on the price difference between beef and other meats [50]. There are other reports of some manufacturers adding beef extract to mask peculiar odors of "bad or off" meat, where meat has aged and deteriorated. Clearly these practices are illegal and pose a serious safety risk to consumers' health. In April 2011, the business sector of China's Anhui Province seized a batch of commercially available "beef extract" additives that had been used in chicken and pork products, but were subsequently sold as beef. In May 2014, one of the most notorious cases of "beef paste" meat substitution occurred in Guangzhou, China, involving more than 20 million yuan of sales in areas across several provinces and cities [51].

27.3 Control Technologies for Meat Safety

Adequate preservation and control technologies for meat and meat products could maintain its safety and quality. Traditional methods of meat preservation may be based on control by temperature, by moisture and, more directly, by inhibitory processes [48], where the most common technique is heat treatment. Nowadays, more and more new control technologies have emerged, and are likely to be widely used in the Chinese market in future.

27.3.1 Non-Thermal Processing Technologies

The purpose of these emerging meat preservation technologies is not only for the control of microorganisms, but also for the retention or enhancement of meat quality attributes such as texture, nutrition and flavor. In the progress towards a more fresh-looking, high-quality and long-shelf-life meat product, the most investigated new preservation methods for meat are those involving non-thermal processing technologies. Progress in the research and application of non-thermal processing technologies for meat are discussed as follows.

27.3.1.1 High Hydrostatic Pressure (HHP) Processing

HHP processing of foodstuff involves subjecting food materials to static liquid pressures that generally range from 100 MPa to 1000 MPa for a given period of time at a particular temperature. During the time under pressure, and dependent on the actual pressures used, the cell membrane structures are damaged, enzymes are inactivated through protein denaturation and metabolic processes are altered [52]. Such changes can result in the inactivation of microorganisms and parasites, while under specific conditions, can concomitantly improve the texture and other characteristics of meat [53]. The effectiveness of HHP treatment for the inhibition of microorganisms is mainly the result of crystallization of phospholipids in the cell membrane, so as to change the cell membrane permeability [54]. As a consequence, this affects the ion exchange across the cell membranes, modifies ribosomes and cell morphology, reduces the stability of the DNA replication complex and affects the transport proteins in the membrane, causing sub-lethal cell injury. Simultaneously, since HHP also causes protein denaturation, and therefore the inactivation of some enzymes, many of the metabolic processes in microorganisms are inactivated [55]. These changes are enhanced by increasing the pressure, temperature and time of application. Recently in China, considerable research has been performed on HHP treatments of meat and meat products, many relating to ready-to-eat (RTE) meat products [45]. For optimal effectiveness, consideration also needs to be given to the type of meat product and its composition. However, in order to achieve the optimal inactivation of microbial flora and extend the product shelf life, a combination of HHP with other preservation technologies, such as moderate heat, or application of bacteriocins, should be considered [56].

HHP technology has already been commercially implemented in the food industry generally, spreading from its origins in Japan, to the USA and then into Europe, with worldwide take-up increasing almost exponentially since 2000 [57]. It has already been used commercially to ensure the microbial safety of various meats and meat products, particularly for cooked, sliced packaged meats. However, in China, meat products treated with HHP have just entered the initial stage. The current limitation in China is that the local meat industry is relatively unfamiliar with the benefits of the HHP process, and also, there are high capital costs of HHP equipment, together with high maintenance costs. Once the industry accepts the wide range of benefits of HHP and begin use, then they should be well supported by the significant research efforts and focus that is available in China. On this basis we suggest that in the future, HHP technologies will become the most practical sterilization technology of choice for certain products in the meat industry in China.

27.3.1.2 Ionizing Radiation

Ionizing radiation has been scientifically established as a safe and effective treatment for food preservation, which destroys bacterial DNA, so as to damage the whole cell and affect the normal growth and metabolism of microorganisms [33]. γ–Rays derived from ^{60}Co, an artificially induced radioactive isotope, are most widely used in the meat industry. The effectiveness of irradiation is dependent upon the irradiation parameters used and the composition of the product. According to the purpose of irradiation, the dose is selected from high, medium or low, being 20–50 kGy, 5–7.5 kGy and 0.5 kGy, respectively. High doses of radiation are generally effective in killing spore-producing microorganisms in food, so as to achieve relatively sterile products. Medium-dose radiation can effectively be used to eliminate large numbers of asporous pathogenic microorganisms, whereas low-dose radiation can be used for reducing the numbers of spoilage baceria, thus extending the shelf life of food [58]. The maximum doses of radiation applied in meat products are dependent on the state of the meat; whether it is chilled or frozen and whether it is raw or cooked. The China National Standards [59–61] allow different maximum doses for different meats. Currently, 57 countries have approved the use of food irradiation, and more than half a million tons of food are irradiated annually worldwide [62]. Although China has approved the use of irradiation for some meat and meat product applications, there has been only limited commercial uptake by the meat industry. Possible reasons for this include the lack of targeted irradiation process technology standards, necessary supporting technologies and cooperation between the industry sectors. However, because of its easy operation, low cost and effectiveness, this technology is likely to become more important for ensuring safe meat.

27.3.1.3 Other Technologies

To meet consumer demand, several other novel non-thermal technologies are currently being studied for the control of microorganisms in food. These include application of high-pulsed electric fields and ultrasound technologies.

High-pulsed electric field sterilization is a non-thermal technology, where food is subjected to high-intensity electric pulses. Two electrodes are placed into a food, which is then subjected to the electric field for a very short time, initiating a potential difference across the cell membranes. At appropriate levels of application, the cell membranes of microorganisms are damaged, leading to their death and hence sterilization of the food [63]. Because of the structural composition of meat, the application of high-pulsed electric field has not been as effective for sterilization as it has been with liquid foods such as juices and milk. High-pulsed electric field technology in China, as in other countries, is an emerging technology that still requires further consideration for application in the meat industry.

Ultrasound technology uses mechanical vibrations at frequencies of greater than 20 kHz in a suitable transmission medium. Its characteristics include high frequency at short wavelength, which has a strong penetrating force and high power output. Factors affecting the ultrasonic effect include the ultrasound parameters, the transmission medium, additives and the process time [64]. For meat, ultrasound has been used for curing, tenderizing, sterilization and thawing. The effectiveness of ultrasound treatment for sterilization is mainly a result of cavitation, causing micro-jets, localized areas of high temperature and high pressures in the non-homogeneous phase (such as the cell wall and cytoplasm), each of which produces an intense bactericidal action [48].

27.3.2 Chemical and Natural Preservatives

Currently, chemical preservatives are widely used in the meat industry in China and these include organic acids and their salts. The most widely used organic acids for meat preservation in the Chinese market are acetic acid, sorbic acid and potassium phosphate [65]. The reason for their effectiveness is that H^+ ions can affect the normal metabolism of microorganisms, thereby rendering antibacterial effects. Certain salts of these acids have been used for meat because of their ability to increase flavor and prolong shelf-life by inhibiting the growth of microorganisms. Lactate, in the form of sodium lactate, is generally regarded as safe (GRAS) by the FDA and is considered as an effective inhibitory agent because of its ability to lower water activity, as well as there being a direct inhibitory effect of the lactate ion [66].

However, due to the potential health hazards of chemical preservatives, natural antimicrobials such as chitosan, nisin and essential oils have become popular. The natural preservatives are mainly derived from animal and plant raw materials or from metabolic products of some microorganisms (such as LAB). This process has the advantage of being non-toxic, safe and provides broad-spectrum antimicrobial effects for use in the meat industry. Much research has focused on polyphenols derived from commonly consumed plants [67], such as tea and apples. For example, polyphenols extracted from tea have been shown to have a wide range of beneficial effects, including antibacterial activity, where they have been shown to destroy cell membrane structures, react with proteins and have metal ion complexing abilities [68].

Chitosan, a polysaccharide polymer obtained by deacetylation of chitin, has strong, broad-spectrum antimicrobial activity [69]. While chitosan has antimicrobial properties itself, it is very effective when applied as a coating or film on food surfaces. Details of the application and effectiveness of chitosan coatings for meat have been described by Sagoo *et al.* [70]. and by Huang *et al.* [71].

Nisin is a polycyclic antimicrobial peptide that is secreted by lactic acid bacteria during the normal process of metabolism. Although the mechanisms of its antibacterial activity are not understood, it is not absorbed by the human body, and does not interfere with the normal flora in the human intestinal tract. Consequently, it is a safe, effective, non-toxic natural preservative with no known harmful side-effects when used at recommended concentrations. Nisin is typically produced commercially by microbial fermentation, a process that is dependent on the culture conditions, pH, ventilation, mixing and the fermentation mode used [72]. However, since nisin is a narrow-spectrum antibiotic, it is usually combined with other preservatives when used for meat products.

27.3.3 Packaging

Packaging is essential for the protection of meat against microbial contamination and cross-contamination with other hazardous materials, thereby minimizing chemical and microbial spoilage and extending its shelf-life.

27.3.3.1 Vacuum Packaging

Vacuum packaging (VP) is the most common method used for meat and meat products in China for the extension of shelf life, especially for ready-to-eat meat products [73]. By providing an anaerobic environment, VP functions by inhibiting the growth of aerobic microorganisms, thereby minimizing protein degradation of the muscle and oxidative rancidity of fat. However, VP does not inhibit the proliferation of anaerobic microorganisms, which will eventually lead to meat spoilage. In most cities in China, the usual supply of raw meat is in the raw-fresh state where VP is not generally used. Essentially, VP is suitable for long-term storage and for long-distance transportation of chilled meat. Therefore, for this purpose it is used for the initial packaging of meat at the plant and through the storage and transportation chain to the retail market.

27.3.3.2 Modified Atmosphere Packaging (MAP)

MAP usually involves placement of a product on a retail-ready tray sealed with a film having a low gas exchange rate under selected mixtures of non-toxic gases [74, 75]. For meat and meat products, the most commonly used filling gases are oxygen (O_2), carbon dioxide (CO_2) and nitrogen (N_2). Based on different gas proportions, there are three major MAP types, low O_2 MAP, high O_2 MAP and O_2-free controlled MAP for different types of meat. Compared with vacuum packaging, MAP does not have a long shelf-life, but maintains an acceptable color, especially for light-colored meats. The uptake of MAP by the meat industry in China has been slower than in most western countries, but in recent years, raw beef and pot-stewed products have become available commercially. It is expected that this type of packaging for meat products will become more popular in China as supermarket outlets increase.

27.3.3.3 Active Packaging (AP)

AP continues to emerge with the development of modern biotechnologies and material science. It is an innovative concept for food packaging where specific additives are either put inside the package or incorporated into the packaging film. The function of active packaging includes microbial control, antioxidant maintenance, O_2 control and moisture control through active agents that act as oxygen scavengers and antimicrobial agents. In China, active packaging is still in the research phase and is expected to develop with the current trends in meat product development.

27.4 Ensuring Meat is Safe to Eat

Recently, concern about meat safety issues in China has been raised by the government, the media and consumers. The whole meat production and supply system consists of a long, complicated, multi-dimensional chain, beginning with breeding and animal production, right through to the final meat product at retail sale. Therefore, ensuring safe meat requires the combined efforts of the government regulators and all industry participants involved in the chain. To address this, a series of effective steps have been taken to strengthen the quality management of meat safety and the establishment of a meat traceability system in China.

In Australia, Meat and Livestock Australia (MLA), the industry body responsible for beef, sheep and goat production, has developed a comprehensive system of accreditation for the assurance assessment of each of the individual stages involved in the production and processing of meat through to the consumer, which is ultimately linked to their traceability system. Although this process was designed for the export market, since the major processors make up the greatest portion, much of the domestic product is assessed in a similar manner. For example, certification and validation is required on-farm and in feedlots for food safety and quality assurance, which includes safe and responsible animal treatment, feed and water safety, use of veterinary medications and pesticides, as well as property risk assessment. Processing plants operate under the Australian Government Legislation and Standards, with health certification provided by the Australian Quarantine Inspection Service (AQIS). Assessment and monitoring programs within plants include product hygiene indicators, a generic *E. coli* and *Salmonella* monitoring program (ESAM) and the National Residue Survey (NRS). Government legislation underpins the National Livestock Identification System (NLIS) in all meat export plants.

A similar system has been developed for the provision of safe pork products to consumers through a similar system (PigPass), administered by Australian Pork Limited (APL) and based on the NLIS (Pork).

27.4.1 Safe Production Technology Systems

The "safe production technology system" of the whole meat industry chain is an integrated innovative system for the safe production of meat during the entire process from production to retail sales. The international food safety management model addresses the whole process of management, from farm to table, so as to minimize food-borne hazards and is based on the principle of prevention. The UN has recommended that China adopt the Hazard Analysis and Critical Control Points (HACCP) system as a national food safety policy, and introduce good practices in all food sectors (e.g. Good Agricultural Practices (GAP), Good Veterinary Practices (GVP), Good Manufacturing Practices (GMP) and Good Hygiene Practices (GHP)) [76]. The concepts of HACCP have gradually gained acceptance, shifting the primary means of achieving food safety to the prevention of hazards, rather than the final inspection of products. Regulatory inspection authorities in China have established requirements for the meat industry to improve and strictly implement GMP, requiring enterprises to commence HACCP programs within a given time period. Furthermore, the HACCP program will take into consideration the distinctiveness of each meat product in China, as well as factors related to the production process.

27.4.2 Trace-Back Processes and Technologies

The International standard ISO8402 defines traceability as: "the ability to verify the history, location, or application of an item by means of documented recorded identification."

For the meat industry involving larger animals (beef, sheep and pigs), this system allows an animal to be labeled at birth with a unique identification, thus enabling it to be identified at each step during the whole supply chain, from breeding, production, transport, slaughtering, cutting, packaging and storage, right through to the consumer. Establishment of such a system allows the collection of information at each step of the chain by using an integrated information management system [77]. Immediately after China's accession to the World Trade Organization, a trace-back system was established for the meat industry based on an understanding of international procedures. In 2002, the Ministry of Agriculture issued a notice on the implementation of the label system, which marked the beginning of its operation in China. In 2007, the first use of the global universal identity system (GSI system) was piloted in Beijing, enabling consumers to determine basic information on the origin of food by bar code scanning of batch numbers provided on packaged food [78]. Since 2010, the Ministry of Commerce and Finance undertook a number of pilot studies on traceability systems for the distribution of meat and vegetables in some large- and medium-sized cities and this has shown promising results. Depending on the information required, traceability systems in different regions of the world may each have a different emphasis that necessitates different applications of tracking technologies. For example, an elaborate traceability system based on the National Livestock Information System electronic ear tagging for beef and sheep meat has been developed by MLA, enabling meat to be traced back from carton to the farm, and under certain circumstances, even to the individual animal. The barcode information can provide inputs on feed, feed additives, veterinary pharmaceuticals and packaging materials used. In recent years, in order to achieve optimal tracking and tracing, many advanced technologies have been studied, such as the electronic ear tag, RFID, iris scanning and DNA analysis [79, 80].

For a more generic system, a multi-element analysis (indicators of geographical and geological location) and multi-isotope analyses (indicators of plant dietary material and geographical location) are also being established, allowing partial determination (or elimination) of meat origin. In China there are a number of research groups actively working in this area. Multi-element analysis, near-infrared reflectance spectroscopy (NIRS) or stable isotope analysis either used alone, or in combination, have successfully been used for determining the origin of various meats (mutton, lamb, beef and poultry) from different regions of China [81].

27.4.3 The Regulatory System in China

In view of the ongoing importance of meat safety in China, the Government has made great efforts to monitor meat safety procedures, where plans and systems have been rapidly implemented, for example the Animal Labeling and Disease Traceability System, the National Monitoring and Control Plan on Animal Drug Residues in Animals and Animal Products, and the Surveillance Plan on Drug Resistance of Animal-Origin Bacteria [82]. In 2009, the Food Safety Law of the People's Republic of China was adopted, which was accompanied by the Implementation Rules of the Food Safety Law. Also, many standards for various food industries have been established and revised by the government, including more than 25 national standards for meat and meat products. However, due to the huge scale of the food industry and the broad administrative structure in China, the implementation of food safety laws is still very difficult to manage. For instance, for the meat industry, regulatory management during the process of animal breeding and slaughtering is the responsibility of the Ministry of Agriculture, whereas the distribution of meat and meat products is supervised by the Ministry of Commerce, which has led to regulatory loopholes across the entire meat chain. Therefore, several areas of food safety have been developed separately. These include the establishment of a tracking system, the formulation of a regulatory system with a clear chain of command among different regulatory bodies and the adoption of common safety standards. Simultaneously, a new department has been established for food safety, which coordinates the national efforts to monitor hazard factors. On October 13, 2011, the China National Center for Food Safety Risk Assessment (CFSA) was established with the approval of the State Commission Office for Public Sector Reform.

27.5 Summary

In China today there is an expectation that not only should meat be nutritious, but also must be of high quality and safe. Currently, consumer awareness of food safety is high and the appropriate authorities have responded to this promptly. Across China now, there are major companies processing, packaging and distributing large quantities of meat to very high standards. These changes have resulted in a major turnaround for the industry over relatively few years. In this chapter we have summarized the major hazards that affect meat safety, such as chemical, physical and biological hazards, and have reviewed a number of control measures to ensure meat safety, with a view to providing a theoretical basis for the safe production of meat. Through a combination of innovative legislative and regulatory actions, public engagement and renewed commitments, continual improvements in meat safety in China are anticipated.

References

1 Zhou G.H., Zhang W.G., and Xu X.L. (2012) China's meat industry revolution: Challenges and opportunities for the future. *Meat Science*, 92, 188–196.

2 National Bureau of Statistics of China. (2014) China Statistical Yearbook 2014. http://www.stats.gov.cn/tjsj/ndsj/2014/indexch.htm (accessed November 2016).

3 Liu C.C. (2009) Analysis of the status and countermeasures of meat safety. *Anhui Agricultural Science Bulletin*, 15(20), 135–136 [in Chinese].

4 Yan T.C., Xiao D., Wang B., *et al.* (2013) Epidemiological characteristics of 130 human avian influenza A (H7N9) cases in mainland China. *Chinese Journal of Disease Control and Prevention*, 17(8), 651–654 [in Chinese].

5 Kim M. (2012) *Chemical Contamination of Red Meat*. Woodhead Publishing Limited, 17, 447–461.

6 Jin S.K. and Jin Y.G. (2011) A review of the main affecting factors and control measures of meat safety. *Meat Research.*, 25(4), 46–49 [in Chinese].

7 He J.L., Li K.X., Yu J.L., and Liu C.L. (2006) The status of the residues of animal medicine in animal food and suggestions for it. *Food Research and Development*, 27(6), 176–191 [in Chinese].

8 Feng Y.H. and Kan J.Q. (2011) The main factors and control measures of the safety of meat. *Meat Industry.* 11, 43–46 [in Chinese].

9 Ministry of Agriculture. (2002) The list of drugs prohibited in animal feeds and drinking water. Announcement by the Ministry of Agriculture of PR China, No. 176, http://www.moa.gov.cn/zwllm/tzgg/gg/201104/t20110422_1976307.htm (accessed November 2016).

10 Surhone L.M., Timpledon M.T., and Marseken S.F. (2010) *Ractopamine*. Betascript Publishing, Belgium.

11 Bottemiller H. "Codex Adopts Ractopamine Limits for Beef and Pork"(July 6, 2012). *Food Safety News.* 2014.

12 Ractopamine. *Gazette APVMA 7*, 1 July 2003 p20.

13 Dale F.; USDA Economic Research Service, May 04, 2015. "U.S. Agricultural Trading Relationship with China Grows."

14 Export Slaughter Intervals (ESIs) of veterinary chemicals for use in cattle. September 18 2015. http://www.apvma.gov.au (accessed November 2016).

15 Export Slaughter Intervals (ESIs) of veterinary chemicals for use in sheep. September 18 2015. http://www.apvma.gov.au (accessed November 2016).

16 Cattle and growth hormone promotants. http://www.mla.com.au (accessed April 2016)

17 Yu Z.F., Zhao L.Q., Zheng J.J., and Wang Z.A. (2012) Safety analysis and control measures of meat products. *Food Science and Technology* 37(1), 135–137 [in Chinese].

18 Wang T.L., Li J. and Lin Q.P. (2006). Study on compound phosphates in meat and meat products. *Food Science*, 27(12), 694–696 [in Chinese].

19 Standardization Administration of the People's Republic of China (2011). *National Food Safety Standards, Standards for Uses of Food Additives*, GB 2760-2011 [in Chinese].

20 Bauer F. (2014) Residues associated with meat production. *Encyclopedia of Meat Sciences*, 3, 1187–1192.

21 Wang X. (2014) The ubiquity of nitrite in meat products. *Guangxi Quality Supervision Guide Periodical*, 5, 48–49 [in Chinese].

22 Li C.B., Zhou G.H., Xu X.L. *et al.* (2015) A doubt about the World Health Organization's report linking red and processed meat to cancer. *Meat Research*, 29(12), 1–5 [in Chinese].

23 Nahla A.G., Ahmed R., Zein S.I., *et al.* (2008) The induction of cytochrome P450 1A1 by Sudan Dyes. *Journal of Biochemical and Molecular Toxicology*, 22(2), 77–84.

24 Haritash A.K. and Kaushik C.P. (2009). Biodegradation aspects of polycyclic aromatic hydrocarbons (PAHs): A review. *Journal of Hazardous Materials*, 169(3), 1–15.

25 Louis E.D., Zheng W., Jiang W., *et al.* (2007). Quantification of the neurotoxic beta-carboline harmane in barbecued/grilled meat samples and correlation with level of doneness. *Journal of Toxicology and Environmental Health.* 70(12), 1014–1019.

26 Chen X.Y. and Zhu R.J. (2010) The formation of flavor, harmful substances and control methods in smoked and baked meat. *Science and Technology of the Food Industry.* 31(5), 405–413.

27 Xu Y., Cui B., Ran R., *et al.* (2014). Risk assessment, formation, and mitigation of dietary acrylamide: Current status and future prospects. *Food and Chemical Toxicology*, 69, 1–12.

28 Peng Z. (2010) Meat pollution and its control measure. *Meat Research.* 11, 37–40 [in Chinese].

29 Jiang L.S. (2010) The main factors affecting the safety of meat and control measures. *Meat Research.* 9, 28–31 [in Chinese].

30 Herrera I.R. and Donoghue D.J. (2012) *Chemical Contamination of Poultry Meat and Eggs*. Woodhead Publishing Limited, 17, 469–497.

31 Standardization Administration of the People's Republic of China (2012). *Limit Standard for Contaminants in Food*, GB 2762-2012 [in Chinese].

32 Zhang C.J. (2012). How far is heavy metal pollution in meat from us? *Food Safety.* 3, 44–45 [in Chinese].

33 Sofos J.N. (2014) Food safety management, Chapter 6 in *Meat and Meat Products.* 119–162.

34 Newton, K.G., Harrison, J.C.L., and Wauters, A.M. 1978. Sources of psychotrophic bacteria on meat at the abattoir. *Journal of Applied Bacteriology*, 45, 75–82.

35 Aiyegoro O.A. (2014) Microbial contamination of processed meat in *Encyclopedia of Meat Sciences*, Volume 2, 289–293.

36 Parlapani F.F., Haroutounian S.A., Nychas G.J.E., and Boziaris I.S. (2015) Microbiological spoilage and volatiles production of gutted European sea bass stored under air and commercial modified atmosphere package at 2°C. *Food Microbiology*, 50, 44–53.

37 John N. S. (2014) Safety of food and beverages, meat and meat products in *Encyclopedia of Food Safety*, Volume 1, 268–279.

38 EFSA (European Food Safety Authority). (2011) *Scientific opinion on the public health hazards to be covered by inspection of meat (swine)*, http://www.efsa.europa.eu/en/efsajournal/doc/2351.pdf (accessed November 2016).

39 Zhou G.H., Xu X.L., and Liu Y. (2010) Preservation technologies for fresh meat: A review. *Meat Science*, 86, 119–128.

40 Feng Y.F., Wu S.Y., Varma J.K., *et al.* (2013) Systematic review of human listeriosis in China, 1964–2010. *Tropical Medicine and International Health*, 18(10), 1248–1256.

41 Standardization Administration of the People's Republic of China (2013). *Limit Standard for Pathogenic Bacteria in Food*, GB 29921-2013 [in Chinese].

42 Hugh P. (2010) Escherichia coli O157, *Lancet*, 376(9750), 1428–1435.

43 Liu X.B, Yang J.C., Jin H.Q., and Xu J.G. (2007) Epidemiological investigation of entero-hemorrhagic *Escherichia coli* O157: H7 infection status in Xuzhou City of Jiangsu Province from 1999 to 2006, *Disease Surveillance*, 22(8), 516–518.

44 Xu X.Y., Subbarao K., Cox N.J., and Guo Y.J. (1999) Genetic characterization of the pathogenic influenza A/Goose/Guangdong/1/96(H5N1) virus: Similarity of its hemaglutinin gene to those of H5N1 viruses from the 1997 outbreak in Hong Kong. *Virology*, 261, 15–19.

45 Zhang D.F., Zheng L.J., and Wu F.T. (2013) Application of UHP technology in meat product technology. *Meat Industry*, (7), 50–53 [in Chinese].

46 Yu Z.F., Zhan L.Q., Zheng J.J., and Wang Z.A. (2012) Safety analysis and control measures of meat products. *Meat Research*, 37(1), 135–137 [in Chinese].

47 Gao J. (2009) Research on the safety of plastic food packaging materials and the differences in standards between China and other countries. Doctoral thesis [in Chinese].

48 Zhou G.H., Xu X.L., and Liu Y. (2010) Preservation technologies for fresh meat: A review. *Meat Science*, 86, 119–128.

49 Feng S.H. and Kan J.Q. (2012) The main factors affecting the safety of meat and its control measures. *Meat Industry*, 11(11), 43–46 [in Chinese].

50 Qiu S. (2013) Uncover the true face of "beef extract." *Chemicals and Life.* 100-101 [in Chinese].

51 Sina Finance. 2014. http://finance.sina.com.cn/ consume/puguangtai/20141215 /22 0021081654.shtml. (accessed December 2014).

52 Chen, J.H., Ren, Y., Seow, J., *et al.* (2012) Intervention technologies for ensuring microbiological safety of meat: Current and future trends. *Comprehensive Reviews in Food Science and Food Safety*, 11(2), 119–132.

53 Garriga, M. and Aymerich T. (2009) Advanced decontamination technologies: High hydrostatic pressure on meat products. *Safety of Meat and Processed Meat*, Food Microbiology and Food Safety Series, Springer, 183–208.

54 Zhang Y., Duan X.C., Li S.F., *et al.* (2007) Influence factors of sterilization and deactivation enzyme of ultra-high pressure processing. *Food Research and Development*, 28(7), 140–144 [in Chinese].

55 Cheftel J.C. (1995) Review: High-pressure, microbial inactivation and food preservation. *Food Science and Technology International*, 1(2), 75–90.

56 Han Y.Q. (2011) Application of high pressure treatment to improve the preservation of cooked ham. Doctoral Dissertation of Nanjing Agricultural University [in Chinese].

57 Pereira R.N. and Vicente A.A. (2010) Environmental impact of novel thermal and non-thermal technologies in food processing. *Food Research International*, 43, 1936–1943.

58 Ehioba R.M., Kraft A.A., Molins R.A., *et al.* (1988) Identification of microbial isolates from vacuum-packaged ground pork irradiated at 1 kGy. *Journal of Food Science*, 53, 278–279, 281.

59 Standardization Administration of the People's Republic of China. (2001). *Code of Good Irradiation Practice for Chilled Packaged Pork Cuts to Control Pathogens and/or Extend Shelf-Life*, GB/T18526.7-2001 [in Chinese].

60 Standardization Administration of the People's Republic of China. (1997) *Hygienic Standard for Irradiated Frozen Packaged Meat of Livestock and Poultry*, GB 14891.7-1997 [in Chinese].

61 Standardization Administration of the People's Republic of China. (1997) *Hygienic Standard for Irradiated Cooked Meat of Livestock and Poultry*, GB 14891.1-1997 [in Chinese].

62 Nam K.C., Lee E.J., Ahn D.U., and Kwon J.H. (2011) Dose-dependent changes of chemical attributes in irradiated sausages. *Meat Science*, 88(1), 184–188.

63 Chen M.L., Xiong G.Q., Geng S.R., *et al.* (2008) Effects of high-strength pulsed electric fields on pathogenic microorganisms from meat. *Journal of Wuhan University of Science and Engineering*, 21(12), 23–26 [in Chinese] .

64 Ma S.W., Wang X.Y., Li J., and Zhang M.Y. (2011) Ultrasonic sterilization mechanism and its influencing factors. *Journal of the Xi'an University of Posts and Telecommunications*, 2, 39–41.

65 Houtsma P.C., Wit J.C.D., and Rombouts F.M. (1993) Minimum inhibitory concentration (MIC) of sodium lactate for pathogens and spoilage organisms occurring in meat products. *International Journal of Food Microbiology*, 20, 247–257.

66 Wang J., Wang X.C., and Liu Y. (2013) A review of applications of plant polyphenols in meat products. *Meat Research*, 27(2), 37–41 [in Chinese].

67 Du W.X. and Olsen C.W. (2011) Physical and antibacterial properties of edible films formulated with apple skin polyphenol. *Journal of Food Science*, 76(2), 149–155.

68 Li X.F. (2009) Study on the antimicrobial activity and mechnism of chitosan. Doctoral dissertation of Lanzhou University [in Chinese].

69 Sagoo S., Board R., and Roller S. (2002) Chitosan inhibits growth of spoilage micro-organisms in chilled pork product. *Food Microbiology*, 19, 175–182.

70 Huang Y. and Liu L. (2010) Study on preservation of chitosan and its application in chilled meat preservation. *Progress in Veterinary Medicine*, 31(S), 63–65 [in Chinese].

71 Yi S.L. (2004) Studies on nisin production using distiller's grain from high gravity alcohol fermentation. Masters thesis of Jiangnan University [in Chinese].

72 Brody A.L. (1989) Microbiological safety of modified/controlled atmosphere/vacuum packaged foods, in *Controlled/Modified Atmosphere Vacuum Packaging of Foods*, Trumbull, CT: Food and Nutrition Press, Inc. 159–174.

73 Young L.L., Reviere R D., and Cole A.B. (1988) Fresh red meats: a place to apply modified atmospheres. *Food Technology*, 42, 65–69.

74 Gill C.O. and Molin G. (1991) Modified atmospheres and vacuum packaging in NG Russel, GW Gould (eds.) *Food Preservatives*, Blackie, London, 172–199.

75 Lutters D. and Klooster R.T. (2008) Functional requirement specification in the packaging development chain CIRP. *Annals ofManufacturing Technology*, 57(1), 145–148.

76 Ma H.W. and Wang S.X. (2006) Traceability system for meat products under food safety circumstance. *China Safety Science Journal*, 16(11), 5–8 [in Chinese].

77 Lehr H. (2013). Recent patents on food. *Nutrition and Agriculture*, 5, 19–34.

78 Liu Y.T., Luo Q.K., Yang Y., and Qian H. (2005) Establish traceability system to ensure food safety of meat. *Meat Hygiene*, 7, 32–24 [in Chinese].

79 Davis J.R. and Dikeman M.E. (2002) Practical aspects of beef carcass traceability in commercial beef processing plants using an electronic identification system. *Journal of Animal Science*, 80(2), 47–48.

80 Chao K.L., Kim M.S., and Chan D.E. (2014) Control interface and tracking control system for automated poultry inspection. *Computer Standards and Interfaces*, 36(2), 271–277 [in Chinese].

81 Zhao Y., Zhang B., Guo B., *et al.* (2016) Combination of multi-element and stable isotope analysis improved the traceability of chicken from four provinces of China. *CyTA - Journal of Food*, 14, 163–168.

82 Ministry of Agriculture. (2010) *Animal Health in China*. Bureau of Veterinary Medicine, Beijing [in Chinese].

28

A New Epoch of Dairy Product Safety in China

Yujun Jiang[1] *and Jin Yue*[2]

[1] *Northeast Agricultural University, China*
[2] *Shanghai Jiao Tong University, China*

28.1 Food Safety is the Top Priority for Dairy Products

With rich and balanced nutrients, a dairy product (DP) is such an ideal natural food that it is sometimes called "almost perfect food" or "the white blood" [1]. DPs can supply nutrients such as calcium to the human body. For non-breast-fed infants, formula plays a prominent role in guaranteeing and promoting their body growth and brain development. Some functional dairy food not only has the nutrition of general dairy products, but also has other health-benefit functions, such as regulating digestive tract, improving immunity, reducing cholesterol absorption, lowering blood pressure, and promoting sleep. Owing to this, increasingly diverse DPs have gradually become an indispensable food to many people. The idea of "a cup of milk makes a nation strong" is exerting greater influence on Chinese consumers.

However, because of the rich nutrients, raw milk and DPs, especially liquid DPs under improper storage, are easily contaminated and can breed bacteria, especially pathogenic types such as *Cronobacter sakazakii*, *Staphylococcus aureus*, and *Listeria monocytogenes*. These bacteria can cause decay and deterioration, while pathogenic bacteria can even cause human diseases. The lethality of some fatal bacteria such as *Cronobacter sakazakii* to newborn babies exceeds 30%, especially to those with hypo-immunity. However, the long dairy production chain covers the selection of water sources, the planting of herbage, feed processing, breeding of cows, prevention and treatment of epidemic diseases, production of raw milk, and the processing, storage, and sale of DPs. Some DPs, such as infant formula require the addition of a variety of vitamins, mineral substances, nutrient supplements, and food additives; they are the most well-rounded nutrition processed food from the most complicated of raw materials. Therefore, problems occurring in the raw materials or at any link in the supply chain may exert a great impact on and even serious threat to the safety of the DPs. In comparison with other processed foods, the quality control of DPs is more difficult, and the government's supervision of them is more complicated.

Other countries, as well as China, also suffer from milk poisoning incidents now and then. In January 1999 in Belgium, some 50 kg polychlorinated biphenyls (PCBs)

Food Safety in China: Science, Technology, Management and Regulation, First Edition.
Edited by Joseph J. Jen and Junshi Chen.

contaminated with 1 g of dioxins were accidentally added to a stock of recycled fat used for the production of 500 tons of animal feed. The signs of poultry poisoning weren't noticed until February. The extent of the contamination was not publicly announced until May, when a high content of dioxins was detected in some eggs and chickens. It also appeared that milk, pork, beef, and other related products were also contaminated and more than 2500 poultry, pig and, dairy farms could have been involved. This has resulted in a major food crisis in Europe, known worldwide as the "Belgian PCB/dioxin crisis."

Fonterra of New Zealand announced in May of 2012 that botulism had been identified in whey concentrate produced by a processing plant. Botulism is a serious condition caused by a toxin from *Clostridium botulinum* that causes paralysis of muscles in humans. The contamination had been traced to a pipe and three batches of whey, which were turned into 900 tons of varied food products sold by eight companies in seven countries. Four companies in China had imported these contaminated products, and the General Administration of Quality Supervision of China demanded that these companies recall all the products. By August 2012, the Department of Primary Industries of New Zealand declared that the previously suspected contaminated whey protein powder from Fonterra had been examined again. Neither *Clostridium botulinum* nor botulism were found in the sample. Only *Clostridium sporogenes* had been detected, which would not poison the human body.

Under the present circumstances for food safety in China, concern about the safety of DPs is becoming increasingly extensive and profound. There are two reasons for this: one is that the status of DPs in the eyes of Chinese consumers is becoming increasingly important, the other is the difficulty and complexity of production and supervision of DPs. The safety of DPs is not only the focus of public attention, but also has become the top priority among the entire food industry. Such concerns from the public about the safety of the dairy industry and the improvement of safety in the dairy industry have also become key to its prosperity [2, 3].

28.2 Crises Create Concerns: The History of China's Dairy Product Safety

Over the last decade, with the growth in total output and consumption per capita of DPs, various DP safety issues and events have exerted profound influences on the development of China's DP industry and triggered reflections from the whole of society.

28.2.1 DP Safety Incidents Caused by Raw Milk

The source of milk is essential to DP quality. Dairy farming features high costs, long periods before reward, and high risks, and DP quality is affected greatly by the quality of raw milk, such as its content of protein, fat, vitamins, the number of bacterial colonies, and heavy metals. Occurrence of DP safety issues, to a large extent, is due to slack control of the milk source, which has severely punished China's DP industry.

The worst case was the "melamine" incident in 2008, represented by the Sanlu Group in the Hebei Province. Melamine (chemical formula: $C_3N_3(NH_2)_3$) is an organic chemical compound that falls to the category of triazines, containing nitrogen and a hybrid ring. It is not allowed in food processing. As a severe food safety issue, the melamine incident had a widespread impact on China. It was first discovered in many infants who were consuming baby formula produced by the Sanlu Group; it was then found out that Sanlu Group's formula for infants contained large amount of melamine. It was published that, by eight o'clock on November 27, 22,384 million babies had been screened due to the melamine problem caused by Sanlu; 294 thousand infants/babies had urinary system abnormalities from using Sanlu milk powder or other milk powder; 51,900 infants/babies had to be hospitalized; and 51,039 babies/infants had been discharged from the hospital [4].

This incident seriously damaged the reputation of China's DPs in the world and focused worldwide attention and concern on their safety. A number of countries banned the import of Chinese DPs. In addition, the incident had a shocking impact on China's DP industry. For a very long time, heavy pressure fell on domestic DP, dairy farming, and related industry chains.

In April 2009, "leather milk" and a great quantity of white leather protein hydrolysate was confiscated in Chenyuan Ruye, a dietary company in Jinhua, located within the Zhejiang Province. "Leather milk" is made by adding leather protein hydrolysate into milk to increase its nitrogen content so that it reached the indexes of protein content when examined. Given that hydrolyzed leather protein contains seriously excessive amounts of harmful substances, such as heavy metals, it poses a great danger to the health of consumers. This was a case of raw material adulteration (non-lacto nitrogen-containing compounds posing as lacto-protein), and caused really bad reactions at home and abroad. The consumers again felt cheated, DP safety again was crushed, and the development of China's DP industry was again thrown into crisis.

Between late 2009 and early 2010, melamine resurfaced in the DP market, greatly burdening the entire industry. On the last day of 2009, it was reported that the Shanghai Panda Dairy Company had been using materials containing melamine to produce and sell DPs with excessive melamine contents. The word "melamine" once again stirred the nerves of the nation and the negative image of China's DP safety was once more reinforced.

On December 24, 2011, China's General Administration of Quality Supervision, Inspection and Quarantine (GAQSIQ) published sample results for liquid DPs across the country, which indicated that aflatoxin M1 (1.2 μg/kg) was detected in a batch of Mengniu's pure milk product, exceeding the standard limit of 0.5 μg/kg. The reason was that the cows had ingested fodder contaminated by aflatoxin B1, which was then turned into aflatoxin M1 through hydroxylation.

In the summer of 2012, excessive aflatoxin was detected in Nanshan Beihui milk powder for infants. The main reason remained that the cows had ingested water and fodder contaminated by aflatoxin. The Department of Commerce and Industry inspected five batches of the product manufactured by Hunan Yahua Dairy Co., Ltd., and found all of them contained aflatoxin M1. The products were for infants aged between the ages of six months and three years. One can imagine the concern and anger of the parents involved. The inferior milk source resulted in the cancelling of the production permit of this company. Consumer confidence in DP enterprises wouldn't be restored for a long time.

28.2.2 DP Safety Incidents Caused by Lack of Processing Control

Strict processing control is also essential to DP safety. Loopholes or deliberate misbehavior occurring in the production chain will harm the health of consumers and at the same time damage the reputation of the DP industry in an irretrievable manner.

In 2004, milk powder of inferior quality found in Fuyang in Anhui Province shocked the entire nation and, for the first time, aroused consumer doubt about the quality of domestic milk powder. The most outstanding feature of children using this product was a very big head. Therefore, the incident is also known as the "Big-Headed Doll Incident." The victims were infants who were fed mainly on milk powder. A major ingredient of this inferior milk powder was starch, which supplies few nutrients. Infants fed on it suffered from hematopoietic dysfunction, internal organ failure, and hypo-immunity. Some presented with symptoms such as swollen face, thin legs, festering skin, and other symptoms of serious maldevelopment.

The incident caused malnutrition syndrome in 171 infants, 13 of whom died from complications. This incident fully revealed the absence of morality and regulation in the minds of certain individuals, of enterprise responsibility, and of governmental supervision. Due to the influence of the "Big-Headed Doll Incident," all the DP factories in Leqing in Zhejiang Province were shut down and dairy farmers had to dump over 20 tons of milk produced every day because they had no way to sell them [5].

In 2005 the "Recycled Milk Incident," involving the Guangming Shanmeng Dairy Company in Zhengzhou was also caused by a serious lack of production control. The factory recycled their stored dairy products to produce new products for sale. Such behavior was a serious violation of relevant stipulations and caused very bad influences. The Guangming DP factory then had another issue, the "Future Milk Incident," where the milk was actually produced before its labelled date. The date was labelled as its predicted release date, instead of the real production date. Such misdeeds caused serious doubt about an enterprise that had won awards for nationally famous brands. After the incident, the company's stock price plummeted, its reputation was tarnished, and its quality was questioned. But, the worst outcome was that the abilities of all DP enterprises regarding quality control and self-discipline within the production process were questioned by consumers.

Production control should not be limited to controlling the content of certain parameters. The optimization and supervision of production equipment are important as well. At the end of June, 2012, the Guangming DP factory in Shanghai had alkaline water mixed in their products because their pipes were not properly cleaned, thus causing the "Caustic Soda Gate Incident." Thus, proper and safe operation of equipment in production also plays a key role in DP safety.

As a nutritious culture substrate, DPs breed microorganisms easily. The total number of bacterial colonies is often an index to determine whether an enterprise observes food hygiene regulations. Soon after the "Caustic Soda Gate Incident," sampling results from the Guangzhou Bureau of Commerce and Industry indicated that the total number of bacterial colonies in a 50% fat-reduced cheese slice, which was produced by the Fanguyi Ruzhipin Company (a branch of Shanghai Guangming Cheese and Butter Co., Ltd.), and Guangming cream, which was produced by Aodehua Rupin (Beijing) Co., Ltd., both exceeded the standards. The excess affects the quality and shelf life of DP, so it must be deemed as an important link in DP quality control.

The Yili Company, a large-scale DP enterprise, revealed in June 2012 that its formula milk powder for infants had unusual contents of mercury. Accidental as it was, its brand image was greatly tarnished. The company claimed that a possible cause could be that the milk was polluted by mercury when the whey was desalted. Thus, it can be seen that production control and process inspection are also important measures all DP enterprises should take.

In the last decade, a lot of food safety incidents have happened in the DP industry. Starting with the "Big-Headed Doll Incident" in Fuyang in Anhui Province, one after another safety incidents drew public attention and struck down consumer confidence again and again. In the meantime, a serious impact was also exerted on the development of the domestic DP industry. As of today, consumer confidence still hasn't recovered [6].

28.2.3 DP Safety Disturbances

In addition to the actual DP safety incidents mentioned above, unscientific news speculation, although not food safety issues and of no harm to consumers, causes serious economic loss or damages the image of companies. It also worsens consumers' misconceptions about the safety status of DPs and hinders the healthy development of the industry [7, 8].

In the summer of 2010, phrases such as "Hormone Gate" and "Infant Sexual Precocity" sprang up in the news media and called public attention to milk powder safety. In July 2010, a diagnostic report from Wuhan Children's Hospital read "15-month old female infant grows breasts and detects vulva congestion; it is advised that the infant should stop using milk powder." After the report was published, parents of all three children involved pointed to the Shengyuan Milk Powder product, which their children had been using. After the melamine incident, the "Hormone Gate" of Shengyuan Milk Powder stirred the peace of China's DP industry. Although the Ministry of Health announced its investigation results on August 15 and claimed that premature breast development of infants was not sexual precocity and has nothing to do with the use of Shengyuan milk powder and that Shengyuan milk powder or other milk powder in the market does not have any unusual hormone content, the brand image of Shengyuan was seriously damaged and a great part of its market share was lost, leading to hundreds of million yuan of economic loss. This incident brought disaster to the entire infant formula market in China.

28.2.4 DP Safety Supervision

One after another DP safety issues caught the attention of the Chinese government. While making new rules and regulations to standardize China's DP industry, it also enhanced enterprise supervision and eventually brought down the occurrence rate of DP safety issues.

Before the melamine incident, the Ministry of Agriculture published the National DP Industry's "11th Five-Year Development Planning and Vision for 2020" in February 2005, stipulating and guiding industry management on regional distribution and major projects for DP industry development. Regarding production/processing, the CFDA published "Detailed Rules for the Authorization of DP Production Permits" on October 24, 2006, stipulating the range of licensed products as well as basic production procedures and control of key links by the permit applicant. This detailed rule standardized the establishment of DP enterprises and further advanced DP safety.

At the state level, the State Council published the "Opinion of the State Council for Promoting the Sustainable and Healthy Development of the DP Industry" in September 2007. The National Development and Reform Commission, along with other departments, published the "Policy for DP Industry" in October 2008, including relatively comprehensive requirements and planning from the perspective of macro industry development. Immediately after the melamine incident, the State Council published, on 9 October 2008, the "Rules of DP Quality Safety Supervision and Management (Order of the State Council, Number 536)," exercising strict control over the quality of DP enterprises. Then on 3 November 2008, the Ministry of Health published its opinion on the implementation of the "Rules of DP Safety Supervision and Management," pointing out that national standards for DP safety must be actively revised and that comprehensive coordination of DP safety and investigation of major DP safety incidents should be properly carried out.

In 2009, the Ministry of Agriculture published "Technical Standards for the Standardized Management of Raw Milk Purchase Stations," exerting strict criteria for the purchase of raw milk. This is an important role in ensuring the safety of milk sources and the healthy development of the DP industry.

In 2010, to follow through on the "Rules for DP Safety Supervision" and the "Outline for DP Industry Rectification and Planning," the Ministry of Agriculture, the National Development and Reform Commission (NDRC), the Ministry of Industry and Information, and the Ministry of Commerce investigatied and then published the "National DP Industry Development Plan," analyzing the status of the DP industry, making its development plan, and pointing out its development direction. Also, in April 2010, the Ministry of Health published a series of national standards for DP safety after careful revision, including standards of products, of inspection methods, and of production. Finally, in December 2010, the CFDA published the "Notification regarding Further Enhancing DP Supervision in Food Service," highlighting the supervision/inspection of DP purchase and reinforcing the use of DP supervision/inspection rules.

Through the efforts of all the departments mentioned above, China has so far established a relatively complete system of laws and standards (including national standards, industry standards, local standards, and enterprise standards), which regulate the entire chain of the dairy industry, including dairy farming, DP processing, and product consumption [9, 10].

As for infant formula milk powder, about which consumers and news media are most concerned, on 16 June 2013, the General Office of the State Council transmitted the recommendations submitted by the CFDA concerning "Further Enhancing the Supervision of the Safety of Infant Formula Milk Powder." This is not only an important decision that promotes and guarantees the safety of formula milk powder for infants, and restores consumer confidence in domestic milk powder, but also helps towards a solution for China's food safety issues with baby formula.

On 25 December 2013, the CFDA published the "Detailed Rules for the Inspection of Production Licenses for Infant formula milk powder (2013 Edition)," raising the threshold for entry into milk powder industry and demanded higher requirements for raw materials and additives, product formulas, techniques and procedures, sites, and equipment. It also demands that local enterprises that produce infant formula milk powder must renew their licenses and complete the re-verification procedure before 31 May 2014. Enterprises that cannot obtain a permit have to stop production until they are authorized and are given two years to rectify issues before authorization.

The Chinese government continues to promote and implement DP safety supervision policies, making and revising relevant laws and standards. As a result, China's DP industry is on a path toward healthier development.

28.3 Reinforcing Management and Pursuing Safety: The Present Status of China's Dairy Products

Since 2014, with the release of the new edition of the "Detailed Rules for the Inspection of Production Permit for Infant Formula Milk Powder," the government has tightened its supervision and management of the milk powder industry. Their policies have introduced the following:

- further strengthening of requirements for production conditions of infant formula milk powder, including referring to medicine management methods to manage DP;
- specifying production procedures and techniques;
- improving quality control on raw materials and other ingredients;
- specific requirements for management of the production process, production conditions, employees, and product formulas;
- stressing R&D and inspection abilities; and
- establishing a product traceability system.

To reinforce the inspection of infant formula milk powder, on 28 January 2014, the CFDA issued the "Notification Regarding the Publication of Infant Formula Milk Powder Inspector Names." In order to strictly control production permits for infant formula milk powder and thus guarantee the quality of inspection work, the CFDA entrusted the Food Production Permit Inspection Center to organize the training, examination, and state registration of inspectors specifically for infant formula milk powder. By this, the inspectors and the on-site inspection can be regulated. Any person taking advantage of the inspection to gain unjustifiable interest, to leak commercial secrets, and to engage in paid food production permit consultation will be punished by law.

On 31 March 2014, the CFDA issued the "Notification regarding Inspection of Production Permit for Using Imported Milk Powder for Infant Formula," demanding strict implementation of production permit inspection and laying out a series of specific requirements on production techniques, formulas, and quality of raw milk powder. Standard operating procedures made by manufacturers should be followed when it comes to material selection, raw powder processing, packaging, transportation, storage, and use.

On 30 May 2014, the CFDA stated that 82 enterprises had been granted production permits for infant formula milk powder and another 51 enterprises that failed to pass inspection would stop production. This effort cleaned up the market concerning infant formula milk powder.

Other governmental branches have also issued a series of policies and measures. On 6 June 2014, the Office of the State Council circulated a publication issued by the Ministry of Industry and Information regarding "The Work Plan of Promoting Mergers and Restructuring of Infant Formula Milk Powder Enterprises." For a time, local governments followed through the decisions and arrangements of the Party Central Committee and the State Council, which enhanced cleansing and reorganization of infant formula milk powder enterprises, reinforced supervision, closed some enterprises whose milk sources were not guaranteed and where production skill was falling behind, promoted the industry structure, and elevated the general safety of dairy products. However, diary enterprises were often fragmented and operating independently. Domestic brands still lacked competitiveness and consumer trust. Therefore, the merging and restructuring of infant formula milk powder enterprises became very important. The targets were focused on "improving industry policy and entry standards," "production permit control," "promoting enterprise merging/restructuring through all possible ways," "regulating enterprise merging/restructuring," "supporting the building of a milk source base," and so on. In this way, standardized, large-scale, modernized infant formula milk powder companies were developed. Internationally competitive enterprises will be built and the industry structure will be further optimized.

In August 2014, the General Office of the CFDA solicited advice on "Recommendations (to be revised) Regarding Management of Food Safety Credit Records of Infant Formula Milk Powder Producers." It mentioned that CFDA branches must keep accurate records of basic information about enterprises, information on supervision and management, and information on public supervision. According to the records, CFDA branches can grade the credit level of infant formula milk powder producers and release the results to the public. For discredited enterprises, frequency of inspection and product sampling should be increased.

Milk bars, an emerging industry, were once unsupervised. In April 2015, related regulations were created according to the relevant laws and rules, including "The PRC Food Safety Law," the "Rules for the Supervision and Management of DP Safety," and the "Measures for Administration of Food Service Permits." Detailed rules were laid out regarding personnel management, operation site, equipment, milk source vouchers, transportation and storage, processing, DP samples, dining utensil sanitation, physical examination of working staff, DP inspection, and prohibition of the use of additives by the seller. It was also specified that the production and operation of DP companies should be regulated over such links as the purchase of raw milk, storage, sterilization, processing management, and interval of inspection.

As the supreme law in food safety, "The PRC Food Safety Law" was revised on 24 April 2015 by the NPC Standing Committee. Article 81 stipulates that infant formula food producers should exercise all-process quality control over its products, from raw material to finished product. Each finished batch of infant formula must be inspected to ensure food safety. Also it is stipulated that the raw milk and other ingredients and additives used in infant formula must meet national standards, so that nutrients necessary for infant growth and development can be guaranteed [13].

Although there have not been any DP safety incidents since 2014, some minor issues, inevitably, still turned up. On 5 May 2015, the CFDA released the inspection results of sampling infant formula milk powder in 2014. This round of inspection covered all 100 domestic manufacturers' products and some imported products, sampled 1565 batches, and identified 48 batches of sub-standard products from 23 domestic producers and 4 dealers of imported products [14].

Forty-four batches of domestic samples were identified to be sub-standard. Among them, 23 batches were below the national standards, and 11 batches were considered high risk. A total of 200 batches of imported products were sampled and four batches were deemed below standard, half of which contained risks. The levels of aflatoxin M1, *Enterobacter sakazakii*, bacterial colonies, and nitrates were the main issues in nonconforming products.

In addition, in some samples, the content of vitamin C, chlorine, manganese, selenium, iron, and calcium, or the ratio of linoleic acid to α-linolenic acid did not meet the national standard. In other cases, some labelled nutrients were not consistent with the actual content.

All the products that were below standard were recalled. The related producers and dealers were required to stop production and sale, to find out the causes of safety problems, to conduct thorough reorganization, and to accept legal punishment. Thanks to timely and effective management, this issue did not have a large-scale impact on the overall DP market.

Starting in May 2015, the CDFA has been releasing results of sampling infant formula milk powder. In addition, each provincial branch of the CDFA pays great attention to designated sampling, tightens punishment of sub-standard producers, and recalls products with potential safety risks.

28.4 Metamorphosis in a New Epoch: The Future of DP Safety in China

China's DP industry today is facing multiple stresses and challenges as follows:

1) The moral and legal awareness of production participants remains to be enhanced.
2) Widespread distribution of milk sources, plus low-level managerial skills, still pose potential risks for DP safety.
3) Producers' emphasis on market exploration and equipment investment over process management and personnel training makes DP safety issues still possible.
4) The large number of DP manufacturers, homogeneous products, high budgets for market exploration, and fierce competition, make it hard for producers to always put quality control as the first priority.

China's DP industry must face these problems and weaknesses, and find solutions to the stresses and challenges before it can turn a new page in its developmental history.

Melamine and other DP safety incidents have put China's DP industry through much pain and suffering, from which both the supervising departments, the DP industry, and consumers can learn a lot. First, governmental supervision was reformed, from supervision by multiple departments, which often leads to confusion of jurisdiction, to CFDA/Ministry of Agriculture joint management, aided by health departments providing standards; in addition, supervisory details have become more and more specific and pragmatic. Second, enterprises are becoming more aware of their responsibilities, and are paying more attention to the source of fodder, the quality of raw milk, the standards of auxiliary materials, the processing, and the conditions for transportation and storage [15, 16].

While under more intense interest, stress, and supervisory measures than other food industry enterprises, DP enterprises invest more energy, equipment, human resources, financial means, and care. It is safe to say that DP safety, in general, is getting better and better. China's DPs have become among the safest processed foods, with strict self-exerted control, and the harshest governmental supervision. Last, consumers have also become aware that rumors should not be taken too seriously, that imported DPs which also have safety issues, should not be favored over domestic DPs, and that China's DP safety should be treated with more rationality. This is a new point of departure for China's DP industry after over a decade of problems.

We have reason to believe that as enterprises' safety awareness grows, governmental supervision is actualized, and consumer understanding heads in the right direction, China's DP industry will gradually leave behind those trials and tribulations and step into a new epoch of DP safety in a positive and sound manner.

References

1 Liu Xiaoqing, Dairy product safety status and measures for development. *Henan Science and Technology University*, 2011, 8–21 [in Chinese].

2 Wang Guihua, A study of countermeasures for perfecting china's dairy product safety guarantee system. *China Academy of Agricultural Sciences*, 2007, 12–43 [in Chinese].

3 Shi Ronghua, Half *Chun Qiu* (History) of China's dairy product safety, *Dairy Products and Human Beings*, 2007, 02, 15–18 [in Chinese].

4 Li Yuansong, Zhang Jianjun, and Li Weilin, Relevant study of safe dairy product production, *China Food Safety Magazine*, 2015, 03, 27–28 [in Chinese].

5 Ministry of Health, Published medical treatment status of Sanlu Milk Powder for Infants, website of Ministry of Health, December 2, 2008. http://www.gov.cn/gzdt/2008-12/02/content-1165588. htm (accessed November 2016) [in Chinese].

6 Liu Chengguo, Dairy product safety is the lifeline of dairy products industry. *China's Cow*, 2004, 6, 2–5 [in Chinese].

7 Xu Huiping and Li Cuixia. Analysis of factors affecting China's dairy product safety. *Chinese Food and Nutrients*, 2012, 08, 5–8 [in Chinese].

8 Mao Wenjuan, Wei Dapeng, Li Lijun, and Wang Jianming. Perfecting technical standards and safeguarding China's dairy product safety. *China's Soft Science*, 2005, 09, 30–36 [in Chinese].

9 Sun Hongming, An Jun, Li Xiaoming, and Zhu Guoqiang. Construction of prewarning system for dairy product safety. *Journal of Northeast Agriculture University*, 2013, 05, 98–101 [in Chinese].

10 Yang Xiao, A study of the back-tracking system for dairy product safety on the basis of coordinated supervision between multiple departments. *Southwest Jiaotong University*, 2014,11–63 [in Chinese].

11 Wu Xiaolu and Shi Jinchuan. Dairy product safety supervision under double catch: A viewpoint. *Sixty-six New National Standards for Dairy Product Safety*, 2012 Annual (Tenth) Anthology of Papers from China's Law and Economics Forum, School of Economics, Zhejiang University; Institute of Economy (Center), Shandong University; *Economy Study* editing staff, 2012, 9 [in Chinese].

12 Hou Junqi and Li. Dairy product enterprises' strategic choice based on dairy product safety: A case study of Mengniu Dairy Products Group. *Journal of Northwest Sci-Tech University of Agriculture and Forestry (Social Science Edition)*, 2014, 5 [in Chinese].

13 *The PRC Food Safety Law* (Decree of the Chairman: Number 21), Portal website of the Central Government, 2015-04-25 [in Chinese]. http://www.gov.cn/zhengce/2015-04/25/content_2853643.htm (accessed November 2016).

14 CFDA, Notification regarding Sampling of Infant Formula Milk Powder in 2014, Website of CFDA, May 5, 2015. http://www.cfda. gov.cn/WS01/CL0050/118442.html [in Chinese] (accessed November 2016).

15 Geng Liping, Causes and counter measures for frequent issues of China's dairy product safety. *Journal of Beijing Industry and Commerce University (Natural Science Edition)*, 2012, 1, 74–80.

16 Zheng Haijing and Hou Xiaoxing, A study of governmental supervision of dairy product safety, *Learning Theories*, 2013, 17, 54–55 [in Chinese].

29

The Importance of Food Safety for Fruits and Vegetables

Xiaosong Hu[1], Fang Chen[1], Pan Wang[1] and Zhao Chen[2]

[1] *College of Food Science and Nutritional Engineering, China Agricultural University, Beijing, China*
[2] *Department of Biological Sciences, Clemson University, SC, USA*

29.1 The Present Situation for Fruit and Vegetable Safety, Domestic and Abroad

Fruits and vegetables play important roles in human nutrition and health, particularly as sources of vitamin C, thiamine, niacin, pyridoxine, folic acid, minerals, and dietary fiber. Moreover, many different organizations (WHO, FAO, USDA, EFSA) recommend increases in fruit and vegetable consumption to help reduce the risk of cardiovascular diseases and cancer [1]. Therefore, the market for fresh fruit and vegetable produce has continually grown over the past decade around the world. With increases in consumption of fresh produce, food safety issues are obviously becoming a public concern.

According to the CDC's Food-borne Outbreak Online Database (food tool; http://wwwn.cdc.gov/foodborneoutbreaks/), the number of food-borne outbreaks per year in the US has gradually decreased since 1998. Nonetheless, the number of produce-associated outbreaks still remains high, ranging from 23 to 60 per year during 2004–2012, without a clear trend over this period of time [2]. There were obvious increases in 2006 (57 outbreaks), 2008 (51 outbreaks), and 2011 (60 outbreaks). Moreover, 49 of the produce-associated outbreaks (13%) reported during the years 2004–2012 were multi-state outbreaks. Norovirus was the main cause of produce-associated outbreaks (59% and mainly linked to salad), followed by *Salmonella* (18%), which was the leading pathogen in multi-state outbreaks and was responsible for the majority of sprouts-associated outbreaks. However, in the summer of 2011, a multi-state outbreak of listeriosis linked to whole cantaloupes from Jensen Farms, Colorado, caused 147 infection cases, 33 deaths, and 1 fetal loss in 28 states [3]. This outbreak is considered to be the largest listeriosis outbreak on record and also the largest recent outbreak due to any pathogen in the US [4].

For the EU, based on the EFSA national zoonoses country reports (https://www.efsa.europa.eu/en/biological-hazards-data/reports), the number of outbreaks linked to fresh produce per year ranged from 10 to 42 in 2004–2012 with no discernible pattern emerging. However, there were substantial increases in 2006 (29 outbreaks), 2009 (34 outbreaks), and 2010 (44 outbreaks) [2]. The share of produce-associated outbreaks

Food Safety in China: Science, Technology, Management and Regulation, First Edition.
Edited by Joseph J. Jen and Junshi Chen.

increased from 4.4% in 2009 to 10% in 2010 [5]. Norovirus was the most common pathogen for produce-associated outbreaks (53% and mainly linked to berries), followed by *Salmonella* (20%), which was consistent with the situation in the US. In May 2011, German health authorities began to investigate an outbreak of a novel pathogen, Shiga-toxin-producing *Escherichia coli* (STEC) O104:H4 [6], which caused the highest number of hemolytic-uremic syndrome (HUS) cases associated with a single outbreak. The final case count was 4075 cases (908 HUS cases) and 50 deaths in 16 countries. Initially, German health authorities made wrong assessments of the likely strain of *E. coli* and also incorrectly linked the pathogen to Spanish cucumbers [7]. The traceback investigations by the EFSA finally identified fenugreek seeds imported from Egypt as the source. This outbreak led to negative economic impacts on Spanish vegetable growers, highlighting challenges in investigating outbreaks caused by rare pathogens and with international trade involved [8].

With respect to Canada, the number of reported food-borne outbreaks during 1975–1995 varied significantly from year to year [9]. Fresh-fruit-associated outbreaks in 1985 showed 21 and 55 incident and case reports, respectively, but with no documented cases in 1993. In Australia, fresh produce accounted for 4% of food-borne outbreaks during 2001–2005 [10].

Compared to Western countries, China does not have many outbreaks due to fresh produce since the Chinese do not eat as much raw produce as Westerners and thus have less chances of exposure to produce pathogens. However, chemical contamination can occur at any stage from farm to fork [11]. Water pollution, heavy metals in the environment, excessive use of pesticides, and chemical fertilizers have directly resulted in several food safety incidents over the past few years in China. Chemical residues within fruits and vegetables have become the most important health risk. According to statistics from the Ministry of Health, in 2006, there were as many as 326 incidents of food poisoning caused by excessive pesticide residues in China, with a total number of 2974 people poisoned (66 people died). In 2014, the corresponding data showed 160 incidents of food poisoning, with a total number of 5657 people poisoned (110 people died) (Table 29.1). Moreover, intentional adulteration has occurred in fruit and vegetable products such as fruit juice.

China has made great efforts to improve food safety. The *Food Safety Law of the PRC* was promulgated in 2009. According to statistics in 2009–2014 from the Ministry of Agriculture, more than 95% of the fruit and vegetable samples passed supervision inspections (Figure 29.1). In 2006, the *Agricultural Product Quality and Safety Law* and the *Organization Law of Farmer Special Economic Cooperation* were approved to guide the implementation and supervision of the quality and safety of agricultural products. In terms of the administration of quality and safety of agricultural products, China's government carried out a strategy of "separate supervision and regulation in each section." In addition, various certifications, such as ISO22000, GAP, GMP, and HACCP have developed rapidly.

29.2 Pre-Harvest Routes for Fresh Produce Contamination in Soils

China is the world's largest fruit and vegetable processing country [1, 12]. In 2014, the cultivation areas for fruits and vegetables in China were 1237.14 and 2140.48 million hectaresand the production amounted to 26 142.24 and 76 005.48 million tons, respectively

Table 29.1 A list of factors causing food poisoning in China from 2010–2014.

Reason for poisoning	Number of cases					Number of people poisoned					Number of people dead				
	2010	2011	2012	2013	2014	2010	2011	2012	2013	2014	2010	2011	2012	2013	2014
Microbial	81	78	56	49	68	4585	5133	3749	3359	3831	16	14	16	1	11
Chemical	40	30	21	19	14	682	730	395	262	237	48	57	19	26	16
Toxic animals, plants and mushrooms	77	53	72	61	61	1151	1543	990	718	780	112	51	99	79	77
Unknown	22	28	25	23	17	965	918	1551	1220	809	8	15	12	3	6
Total	220	189	174	152	160	7383	8324	6685	5559	5657	184	137	146	109	110

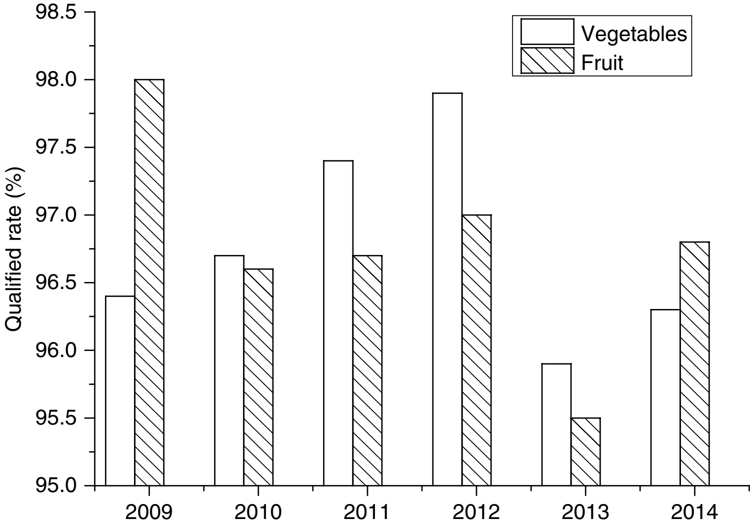


Figure 29.1 Pass (qualified) rate (%) for fruit and vegetable quality and safety tests in China.

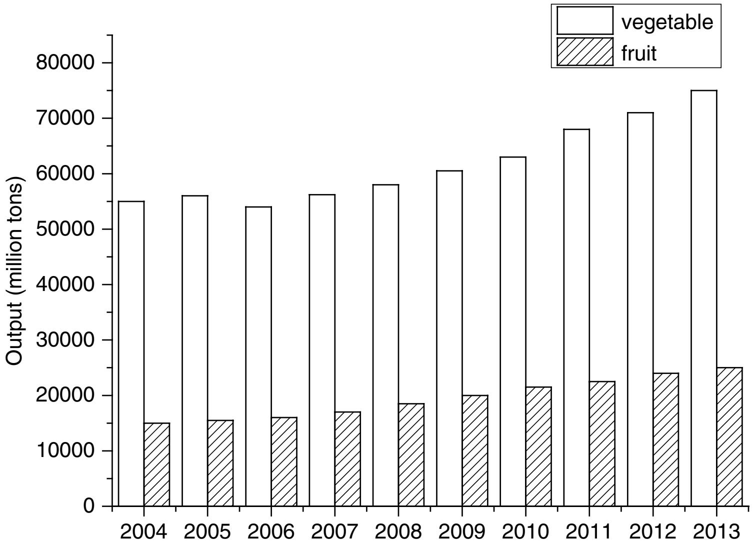


Figure 29.2 Changes in fruit and vegetable output from 2004 to 2013.

(Figure 29.2) [13]. However, hazardous compounds in environment and input residues in agricultural production have become a public concern on health risk.

29.2.1 Environmental Contaminants

Serious heavy metal contamination events have taken place since the 1950s in China, with more frequent occurrences coming in recent years. Metals are selectively concentrated by crops. In particularly, leafy vegetables are more responsive to trace elements in soil, such as cadmium and lead. Ni, Yang, and Long [14] found that cadmium accumulation in crops was linearly related to the level of cadmium in soil. For leafy vegetables, the increase was exponential. It has been documented that nearly 50% of the mean ingestion of cadmium and lead from food involves fruits, vegetables, and cereals [15]. Therefore, accumulation of metals in leafy vegetables not only affect food quality, but are also have present a potential hazard to human health by way of the food chain.

Many surveys have shown heavy metal contamination on crops to be caused by sewage irrigation due to the impending water shortage in China. The emission of industrial wastewater has increased with the rapid economic growth and population increase since the 1970s. The emission of sewage (urban and rural sewage) is greater than 60 billion tons every year, with urban sewage treatment rates reaching 77.5% in 2010, although it is less than 10% in rural areas. With increasing wastewater emissions, sewage irrigation has become an effective measure to alleviate the shortage of water resources and increase agricultural production [16]. However, sewage contains a large number of potentially hazardous materials, including persistent organic pollutants, and heavy metals [17]. Intake of vegetables containing high concentrations of metals has caused detrimental health risks, such as osteoporosis and cardiovascular disease, to the consumer, especially children [18]. In 2013, for the first time, the government prohibited the application of sewage with heavy metals and/or persistent organic pollutants for irrigation [19]. However, policy implementation is challenging, especially in the North China Plain as a result of the lack of availability of good quality water.

29.2.2 Chemical Inputs in Agricultural Production

Fruit and vegetable protection provided by the use of pesticides have made a significant contribution to growth in agricultural productivity. The total consumption of fertilizers and pesticides has increased linearly over time, with usage doubling over the past two decades [20]. Although grain yield grew in the same period, total production has increased only by a quarter, with a yield reduction between 1999 and 2003. After 2003, the government has implemented a series of policies, such as subsidies for seeds, fertilizers, and pesticides, and abolition of the agricultural tax. It was found that usage of pesticides and fertilizers was positively correlated with grain yield and this correlation after 1999 was stronger and of a higher magnitude than before 1999. Due to limited availability of arable land, it is necessary to increase the yield per unit area through the increase of chemical inputs. Although farmers could use fewer pesticides to get higher yields with the implementation of an integrated pesticide management (IPM) program [21], the current production of grain still greatly relies on the use of pesticides and fertilizers.

29.2.2.1 Fertilizers

China is a large consumer of chemical fertilizers. China's grain yield increased 1.7-fold over the past three decades and chemical fertilizer use increased by 3.9 times, with an average annual growth rate of 12.9%. The total fertilizer consumption was 430.0 kg/ha in 2012 [20], whereas the internationally recognized maximum safe usage of fertilizers is 225.0 kg/ha [22]. However, over the same period, many countries have taken measures in order to control and reduce the consumption of nitrogen and phosphorus fertilizers. Chemical fertilizer use has been reduced by approximately 30–50% in Western

European countries since the 1980s. In 2010, the consumption of nitrogen and phosphorus fertilizers were 278.4 and 134.5 kg/ha in China, and only 70.7 and 23.9 kg/ha in the United States [21]. Nitrate is a potential hazard because it can be reduced to nitrite endogenously in plants. This nitrite may result in methemoglobinemia and can react with amines or amides to form a variety of N-nitroso compounds (NOCs), which are potential human carcinogens [23].

Moreover, the utilization efficiencies are 30–40%, 10–20%, and 35–50% for nitrate, phosphate, and potash, respectively, which are much lower than in developed countries, where the nitrate use efficiency can be as high as 70–80%. Up to half the nitrogen applied in China is lost by volatilization, and another 5–10% by leaching. A large number of surveys have indicated that there is a higher nitrate or nitrite content in drinking water in higher cancer incidence areas [24]. Control of nitrate content in drinking water could effectively reduce the incidence of cancer in Linzhou City in Henan Province [25]. In recent years, China's environmental protection policy has paid attention to the reduction of ammonia nitrogen emissions. This has led to increases in measures that convert ammonia nitrogen into nitrate nitrogen in wastewater treatment plants before discharge into environment. These measures may cause more severe nitrate nitrogen pollution.

29.2.2.2 Pesticides

Pesticide residues in the vegetable and fruit sectors is more serious than it is in other sectors. It is the most important concern for consumers. China is the largest pesticide consumer in the world [20]. The total amount of pesticide applied was 1.78 million tons in 2011, which has increased by 2.3 times since 1991, with an average annual growth rate of 11.7%. At the same time, the efficiency of pesticides is only about 30% in China, while it is 50–60% in developed countries [26]. Thus, pesticide residues in agricultural products have become one of the biggest consumer health concerns in China. In recent years, the Chinese government has addressed pesticide production and use issues largely through its regulatory power. The production and use of some high-toxic and high-residue pesticides has been prohibited. The data showed that the overall level of contamination decreased and that the percentage of pesticide residues over prescribed limits declined year by year, from 0.7% in 2003 to 0.5% in 2009. The use of pesticides in agricultural production is tending to be more scientific, reasonable, and feasible.

Pesticide residue testing by firms and sample testing by the government are the two screenings that alleviate potential food safety risks. The Food Safety Law of the People's Republic of China, promulgated on November 1, 2006, explicitly requires that firms engaged in agricultural production should test pesticide residues themselves or through third-party testing organizations. Therefore, pesticide residue testing has become one of the effective measures for food safety control. Nevertheless, the pesticide residue testing system in China is not perfect. Furthermore, it is not sufficient to completely solve food safety problems by just testing for pesticide residues. Creating a traceability system that helps to quickly identify faulty products is of great necessity to firms. To date, a number of firms in China have established sales account systems, and it is now possible to trace firms that provide faulty products. Production records that contain inputs and production management measures, and are recorded by farmers are needed to further and more accurately trace exact responsibility to the appropriate subjects. In addition, one of the main problems in first-stage product processing is the inappropriate use of chemical preservatives, which can be effectively traced by establishing production records. Hence, in this chapter we are also looking at the establishment of production records as a food safety control practice.

29.3 Post-Harvest Routes for Fresh Produce Contamination

Mechanical injury induced by cutting (lettuce, apple, and pear), shredding (carrot, cabbage), dicing (tomato), or peeling (carrot, orange) during harvesting operations occurs for fresh-cut produce. These operations create surfaces upon which enteric pathogens can more easily attach. Cut surfaces of produce also release large amounts of nutrient-laden liquids that are readily utilized by the attached microbes.

29.3.1 Pathogens Associated with Fruits and Vegetables

A number of mechanisms have been advocated as contributing to adhesion of enteric pathogens to food surfaces, including: extracellular polymeric substances; the presence or absence of fimbriae; cell surface hydrophobicity; divalent cationic bridges; and bacterial surface charge. Unfortunately, conclusive evidence for the contribution of these factors is absent due to differences in response by pathogens to attachment and the heterogeneous nature of the various surfaces investigated, as well as the dramatic differences in cell surface composition between different types of produce.

Fresh-cut fruits and vegetables harbor a wide variety of microorganisms, such as bacteria, yeasts, and fungi that cause spoilage (Table 29.2) [27]. An estimated 80–90% of bacteria are Gram-negative, predominantly *Pseudomonas* and Enterobacteriaceae species. Lactic acid bacteria are part of the normal flora of fruits and vegetables and are associated with spoilage organisms, causing unpleasant odors. Yeasts and molds are present in smaller numbers than bacteria, but, when present in high numbers, they can contribute to spoilage of fermented products and the development of soft rot. According to epidemiological surveys, fresh-cut fruits and vegetables can also harbor pathogenic bacteria capable of causing human infections, such as *Listeria monocytogenes*, *Salmonella* spp., and *Escherichia coli* O157:H7 [28]. Many factors can contribute to the contamination of fresh and fresh-cut products with pathogens. Pre-harvest contamination of fruits and vegetables can occur via animals, insects, water, soil, dirty equipment, and human handling. Post-harvest manipulation, wash water, workers,

Table 29.2 Common human pathogens existing in fresh fruits and vegetables.

Categories	Specific microorganisms
Pathogenic bacteria in soil	*Clostridium botulinum*, *Listeria monocytogenes*
Pathogenic bacteria in faeces	*Salmonella*, *Shigella*, *Escherichia coli* O157:H7
Pathogenic parasites	*Cryptosporidium*, *Cyclosporiasis*
Pathogenic viruses	Hepatitis A virus, Enterovirus, Norwalk-like virus

packing materials, process equipment, and transportation vehicles are also potential sources of contamination.

Due to the occasional presence of pathogens on fruits and vegetables, several outbreaks associated with the consumption of these products have been reported. For example, melons, tomatoes, pears, watermelons, strawberries, mangoes, grapes, spinach, and lettuce have been implicated in outbreaks caused by *Salmonella* spp. and *E. coli* O157:H7 [29]. *L. monocytogenes* has been implicated in outbreaks linked to contaminated lettuce, broad-leaved endive, broccoli, radishes, cabbages, potatoes, cucumbers, and melons [30].

29.3.2 Survival and Growth of Pathogens on Fresh Produce During Storage

In general, enteric pathogens are often capable of surviving on produce over the period of distribution. The fate of enteric pathogens on produce during storage is dependent on the storage conditions, including temperature, relative humidity, gaseous composition of the atmosphere, nutrient availability, and presence of competitive bacteria or antimicrobial compounds. In addition, damage to the product often enhances survival and growth of contaminated pathogens. For example, lettuce tissue from heads dropped six feet incurred survival or growth of *E. coli* O157:H7 ˜0.5 log greater than in undamaged tissue when stored at ambient temperature for 4 hours, followed by 48 hours of storage at 4 °C. Slicing methods that shear or tear the tissue also led to consistently higher *E. coli* and *L. innocua* counts on packaged vegetables (carrots, and iceberg and butterhead lettuces) during storage than slicing manually with a razor. Biological damage is also of concern as it often leads to enhanced survival or growth of enteric pathogens. For example, produce that has been affected by soft rot is more conducive to growth of *Salmonella* than non-diseased produce [31]. Nevertheless, significant differences in survival of *L. monocytogenes* strains occurred in coleslaw, with most strains exhibiting decreases in population during storage at 8 °C. However, populations of serotype 1/2a strain 269 increased on coleslaw during storage at 8 °C [32].

29.3.3 Packaging Technology

Modern methods of storage, including physical methods, chemical methods, and biological methods, such as low-temperature storage, controlled atmosphere storage, radiation storage, chemical antisepsis, antagonistic storage of microbes and their metabolic products, genetic engineering technology, and so on. These methods can maintain the freshness of fruits and vegetables to some extent, but not completely (Table 29.3).

Modified atmosphere packaging (MAP) of fresh products consists of altering the atmosphere inside the package by the natural interaction between the respiration rate of the product and the transfer of gases. The desired atmosphere can be created using either active or passive modified atmosphere packaging. Active MAP is based on the displacement or replacement of gases in the package, or the use of gas scavengers or absorbers to establish a desired mixture of gases, while passive MAP is based on the use of a specific packaging film, in which a desired atmosphere develops naturally due to the product's respiration and the diffusion of gases through the film [33].

MAP is used for various types of products, and the specific mixture of gases in the packaging in each case depends on the product type, the packaging materials, and the

Table 29.3 Potential damage existing in the methods of storage and preservation[34].

Methods	Potential Damage
Low-temperature storage	Different fruits and vegetables have certain ranges of endurance of low temperature. If the temperature is too far out of the range, it will change the nutrition and shape of the products and affect the food safety. This is called low-temperature damage.
Controlled atmosphere storage	This kind of damage is caused by different proportions of gas components, which would destroy the sensory properties of fruits and vegetables, accelerate the loss of nutrients, and even produce substances harmful to human health. This damage also contributes to the multiplication of some anaerobic bacteria on fruits, threatening the safety of fruit and vegetable products.
Hypobaric Storage	Each kind of fruit and vegetable has a certain endurance limit for low pressure preservation. If the pressure were beyond the limit, the nutrition and quality would be damaged.
Radiation storage	A range in radiation amount is an important factor affecting fruit and vegetable nutrition and quality. A relatively low amount of radiation should be chosen to process fresh fruits and vegetables, otherwise, lots of nutrients would be lost, with the fruits and vegetables becoming soft under radiation.
Chemical antisepsis	An inappropriate solvent concentration not only cannot maintain the quality of fruits and vegetables, but will accelerate deterioration.
Antagonistic storage	The inducing effects of antagonistic microorganisms will definitely change physiological metabolism of fruits and vegetables, such as inducing some secondary metabolites to resist disease, enzymes for defense, and structural resistance.
Storage with bionic preservatives	The researches about the inhibitory effects of natural products on pathogenic bacteria have always been done in culture media, but practice has shown that to obtain the inhibitory concentration acquired in culture media from experiments, the amount of preservative should be multiplied in practical application.
Genetic engineering	Modifying, silencing, or altering the expression activity of some genes may change physiological processes and the quality of fruits and vegetables.Whether it is safe to eat genetically modified fruits and vegetables is a problem needing an urgent solution.

storage temperature. If the permeability (for O_2 and CO_2) of the packaging film is adapted to the product respiration, an equilibrium modified atmosphere is established in the package and the shelf-life of the product increases.

In addition, temperature control is also very important to an effective MAP system. Temperature strongly affects the respiration rate and the permeability of gases through packaging films, allowing atmosphere changes to occur inside the packaging [35]. Furthermore, storage temperature is one of the most important factors in the survival and growth of pathogens on fresh-cut fruits and vegetables. Maintaining produce temperature at or below 4 °C throughout the cold chain is essential for microbial safety.

During fruit and vegetable processing, the intracellular components released from broken cells may enhance bacterial growth. Therefore, specific measures and interventions should be implemented to minimize the risk of infection associated with the consumption of contaminated fresh-cut fruits and vegetables. Nowadays, MAP in combination with refrigeration can be used as a mild preservation technique to enhance the safety of minimally processed products. However, the effect of MAP on microorganisms can vary, depending mainly on the storage conditions and the type of product.

29.3.4 Transportation

Currently, the supply of fruit and vegetable products in China is still stuck in the traditional mode of storage and transportation, as cold-chain logistics are not well developed. In 2012, there were 0.3 million refrigerated carriers in China, while in America and Japan the number was 2 million and 1.2 million, respectively [36]. The ratio of refrigerated carriers to freight vehicles in China is only 0.3%, while in America the ratio is 0.8–1.0%, and Germany and other developed countries have a ratio around 2–3%.

Every year, the amount of perishable goods transported by railway in China is about 100 million tons, but only 25% of the total products are transported in refrigerated trains. The total amount of refrigerated vehicles used for highway transportation is only 0.4 million and the amount of perishable goods transported by refrigerator cars occupies less than 20%. China has over 200 refrigerated transportation ships, with a total capacity of 1 million tons, however only 1% of the total products are transported by waterway. With the exception of export fruits and vegetables transported under refrigeration, domestic fruits and vegetables are generally transported at ambient temperature (Table 29.4).

Compared to the increasing output of fresh produce, the cold chain logistics of fruits and vegetables in China are very deficient, thus developing these is still a most important and pressing task for China.

29.4 Global Perspective

For the control of food safety of fruits and vegetables, a worldwide traceability system has been implemented. We have emphasized that agricultural production is the source and the most critical stage as a result of the transmission of food safety problems along a supply chain. The inappropriate use of fertilizers and pesticides and agro-ecological environmental pollution results in chemical and microbiological contamination of fresh produce at source. Thus, food safety control practices at the production stage essentially involve three aspects: (i) environmental inspection, (ii) input, and (iii) production management.

Table 29.4 Cold-chain circulation and transportation amounts from 2010 to 2014 in China [37].

Year	Amount of production (billion tons)	Amount of cold-chain circulation (billion tons)	Amount of cold-chain transportation (billion tons)
2010	8.65	0.51	1.38
2011	9.07	0.66	1.60
2012	9.50	0.85	1.85
2013	9.86	1.13	2.14
2014	10.00	1.46	2.47

References

1 Oliveira, M., Abadias, M., Usall, J. *et al.* (2015) Application of modified atmosphere packaging as a safety approach to fresh-cut fruits and vegetables: A review. *Trends in Food Science and Technology*, 46 (1), 13–26.

2 Callejón, R.M., Rodríguez-Naranjo, M.I., Ubeda, C. *et al.* (2015) Reported foodborne outbreaks due to fresh produce in the United States and European Union: trends and causes. *Foodborne Pathogens and Disease*, 12, 32–38.

3 Centers for Disease Control and Prevention (CDC) (2012) Multistate outbreak of listeriosis linked to whole cantaloupes from Jensen farms, Colorado (FINAL UPDATE). Available at: http://www.cdc.gov/listeria/outbreaks/cantaloupes-jensen-farms (accessed June 2016).

4 McCollum, J.T., Cronquist, A.B., Silk, B.J. *et al.* (2013) Multistate outbreak of listeriosis associated with cantaloupe. *New England Journal of Medicine*, 369, 944–953.

5 Uyttendaele, M., Jacxsens, L., Van Boxstael, S. (2014) Issues surrounding the European fresh produce trade: a global perspective. In: Global Safety of Fresh Produce: A Handbook of Best Practice, Innovative Commercial Solutions and Case Studies. Woodhead Publishing, Cambridge, UK. pp. 33–50.

6 European Centre for Disease Prevention and Control (ECDC). Outbreak: STEC 0104:H4 2011. http://ecdc.europa.eu/en/healthtopics/escherichia_coli/outbreaks/Pages/default.aspx (accessed June 2016).

7 Buchholz, U., Bernard, H., Werber, D. *et al.* (2011) German outbreak of *Escherichia coli* O104: H4 associated with sprouts. *New England Journal of Medicine*, 365, 1763–1770.

8 CDC. 2013. Outbreak of *Escherichia coli* O104:H4 Infections Associated with Sprout Consumption-Europe and North America, May–July 2011. http://www.cdc.gov/mmwr/preview/mmwrhtml/mm6250a3.htm (accessed June 2016).

9 Todd, E.C.D. (1974–2001) Foodborne and waterborne disease in Canada, annual summaries. Health Products and Food Branch, Health Canada, Ottawa, ON, Canada.

10 Kirk, M.D., Fullerton, K., Gregory, J. (2008) Fresh produce outbreaks in Australia 2001–2006. Board 21. In: 2008 International Conference on Emerging Infectious Diseases: Program and Abstracts. CDC, Atlanta, GA, US. pp. 49–50.

11 Zhou, J.H. (2005) A Study on the Management of Fresh Vegetable Quality and Safety. China Agriculture Press. pp. 129–135 [in Chinese].

12 Wu, Y., Zhao, L., Hong, K.X. *et al.* (2013) Analyzing and reflecting on the status quo of pesticide application to vegetables in China. *China Plant Protection*, 4, 17 [in Chinese].

13 NBS (National Bureau of Statistics of the People's Republic of China) (2013) National data. http://data.stats.gov.cn/workspace/index?m=hgnd (accessed November 2016) [in Chinese].

14 Ni, W., Yang X., Long, X. (2002) Differences of cadmium absorption and accumulation in selected vegetable crops. *Journal of Environmental Science*, 14, 399–405.

15 Islam, E., Yang, X., He, Z. *et al.* (2007) Assessing potential dietary toxicity of heavy metals in selected vegetables and food crops. *Journal Zhejiang University Science*, B8, 1–13.

16 Xia, Z., Li, S. (1985) Characteristics of the distribution of sewage irrigation in China and analysis of its cause of formation. *Geographical Research*, 4, 40–45 [in Chinese].

17 Dere, C., Lamy, I., Jaulin, A. *et al.* (2007) Long-term fate of exogenous metals in a sandy Luvisol subjected to intensive irrigation with raw wastewater. *Environmental Pollution*, 145, 31–40.

18 Liu, G., Liang, C., Du, L. *et al.* (2006) Primary study of heavy metal contamination of soil in the area of Hongtou Mountains. *Chinese Agricultural Science Bulletin*, 22, 364–367 [in Chinese with English abstract].

19 The State Council of China (2013) Arrangement for soil environment protection and comprehensive treatment work in recent period. http://www.gov.cn/zwgk/201301/28/content_2320888.html (accessed November 2016) [in Chinese].

20 NBS (National Bureau of Statistics of the People's Republic of China) (2014) National data. http://data.stats.gov.cn/workspace/index?m=hgnd (accessed November 2016) [in Chinese].

21 FAO (Food and Agriculture Organization) (2010) Fewer Pesticides and Higher Yields and Incomes. http://www.fao.org/news/story/en/item/48883/icode/ (accessed November 2016).

22 Abhilash, P.C., Singh, N. (2009) Pesticide use and application: an Indian scenario. *Journal of Hazardous Materials*, 165, 1–2.

23 IARC (International Agency for Research on Cancer) (2010) Ingested Nitrate and Nitrite, and Cyanobacterial Peptide Toxins. International Agency for Research on Cancer, Lyon.

24 Liu, Z., Zhang, H., Chen, Y. (2014) Ammonia, nitrite and nitrate nitrogen levels in drinking water from area with high incidence of esophageal cancer among Kazakh residents in Yili prefecture of Xinjiang. *Chinese Journal of Public Health*, 30, 940–943 [in Chinese].

25 Han, J., Xu, Z., Xing, H. *et al.* (2007) Influence of water supply improvement on incidence and mortality of esophageal cancer in Linzhou. *China Cancer*, 16, 79–80 [in Chinese].

26 Peng, C.R. (2013) Agricultural Nonpoint Source Pollution Control Theory and Technology. China Agriculture Press, Beijing, pp. 27–35 [in Chinese].

27 Abadias, M., Usall, J., Anguera, M. *et al.* (2008) Microbiology quality of fresh, minimally-processed fruit and vegetables, and sprouts from retail establishments. *International Journal of Food Microbiology*, 123, 121–129.

28 Liu, W., Zhou, Q., Zhang, Y. *et al.* (2010) Lead accumulation in different Chinese Cabbage cultivars and screening for pollution-safe cultivars. *Journal of Environmental Management*, 91, 781–788.

29 Ethelberg, S., Lisby, M., Bottiger, B. *et al.* (2010) Outbreaks of gastroenteritis linked to lettuce, Denmark, Feb 11 2010. *Euro Surveillance*, 15(6), 19–84.

30 Little, C. L., Gillespie, I.A. (2008) Prepared salads and public health. *Journal of Applied Microbiology*, 105, 1729–1743.

31 Wells, J., Butterfield, J. (1997) Salmonella contamination associated with bacterial soft rot of fresh fruits and vegetables in the marketplace. *Plant Diseases*, 81, 867–872.

32 Francis, G.A., O'Beirne, D. (2005) Variation among strains of Listeria monocytogenes: differences in survival on packaged vegetables and in response to heat and acid conditions. *Food Control*, 16, 687–694.

33 Lee, L., Arul, J., Lencki, R. *et al.* (1996) A review on modified atmosphere packaging and preservation of fresh fruits and vegetables: physiological basis and practical aspects. Part 2. *Packaging Technology and Science*, 9, 1–17.

34 Zhao, J., Liu S., Xu F. *et al.* (2013) Factors affecting quality and safetyof fruits and vegetables and their coping strategies. *Journal of Food Safety and Quality*, 6, 1637–1644.

35 Devlieghere, F., Debevere, J. (2000) Influence of dissolved carbon dioxide on the growth of spoilage bacteria. *LWT, Food Science and Technology*, 33, 531–537.

36 Hassan, N.U., Mahmood, Q., Waseem, A. *et al.* (2013) Assessment of heavy metals in wheat plants irrigated with contaminated wastewater. *Polish Journal of Environmental Studies*, 22, 115–123.

37 CCICED (China Council for International Cooperation on Environment and Development) (2006) Environmental Issues and Countermeasures Facing New Rural Development in China. http://english.mep.gov.cn/international_cooperation/CCICED/ (accessed November 2016).

30

Safety of Fats and Oils

Yu Wang[1], Bo-Yang Hsu[2], Chi-Tang Ho[3] and Lucy Sun Hwang[4]

[1] *University of Florida, Lake Alfred, FL, USA*
[2] *Lee-Ming Institute of Technology, New Taipei, Taiwan*
[3] *Rutgers University, New Brunswick, NJ, USA*
[4] *National Taiwan University, Taipei, Taiwan*

30.1 Introduction to Lipids

Lipids are widely defined as any compounds soluble in organic solvents, but not in water. They include fats, oils, fat-soluble vitamins and phospholipids, among others. Lipids are classified into simple lipids without saponification and acyl lipids with saponification. Simple lipids include free fatty acids, isoprenoid lipids and tocopherols, while acyl lipids contain mono-, di- and triacyl glycerols, phospholipids, sphingolipids, glycolipids, diol lipids, waxes and sterol esters. Lipids can also be classified based on their polarity, such as neutral lipids and polar lipids.

Fatty acids and fatty acid derivatives are major classes of lipid. Fatty acids refer to any aliphatic carboxylic acids, which can be released through hydrolysis of the natural fat. They can be classified based on the length of the chain, the additional functional group attached to the chain, and the number, position and configuration of double bonds they contain. When the double bond position is counted from the methyl group site, unsaturated nonconjugated fatty acids can be classified into ω-3 (alpha-linolenic acid type), ω-6 (linoleic acid type) and ω-9 (oleic acid type). Usually, fish lipids are rich in ω-3, and ω-6 can be found in soybean, corn, meat, liver, lard and eggs. Unsaturated fatty acids are easily involved in lipid peroxidation and *trans* fat formation during industrial processing. *Trans* fats have been related to safety issues, which will be discussed later in this chapter.

30.2 Safety of Saturated Fat

Saturated fatty acids and their derivatives are considered as saturated fat. In nature, free saturated fatty acids occur in very small amounts, and most of them are esterified with glycerol to form triacylglycerols. Saturated fat can be found in animal fats and vegetable products such as cream, cheese, butter, coconut oil and palm oil [1].

Food Safety in China: Science, Technology, Management and Regulation, First Edition.
Edited by Joseph J. Jen and Junshi Chen.

There has been a long dispute on the safety issue of saturated fat. Half a century ago, it was believed that consuming less saturated fat would be healthier than consuming more saturated fat. However, based on the epidemiological data and many diet intervention studies, there has been no solid evidence to support the impact of saturated fat on health, particularly on vascular dysfunction [2].

The safety of saturated fat is still a controversial topic, but the World Health Organization (WHO) and many countries have set up guidelines for saturated fat consumption. In 2003, the WHO concluded that consumption of saturated fat was directly related to coronary heart disease (CHD). They suggested controlling the intake of saturated fat to below 10% of total daily energy intake. For high-risk groups, 7% was the recommended level. In 2004, the Centers for Disease Control (CDC) published a statement indicating that Americans needed to continue working to reduce saturated fat intake. Until any clear results are found, it is suggested to follow all the guidelines.

30.3 Safety of *Trans* Fat

Trans fat refers to fats and oils having at least one unsaturated fatty acid with one or more double bonds in the *trans* configuration. In nature, unsaturated fatty acids generally have the *cis* configuration. The structures of *cis* and *trans* configurations of monounsaturated fatty acids are shown in Figure 30.1. In recent years, *trans* fatty acids have attracted much attention, because their consumption even at low levels could cause serious health risks such as CHD, cancer, diabetes and liver dysfunction [3].

30.3.1 Formation of Trans Fat

Recently, it was realized that *trans* fatty acids could not only be obtained exogenously from food intake, but also they could be generated endogenously within the cells. According to recent research, the endogenous generation of *trans* fatty acids, especially in the cell membranes, induced by radical stress is an inevitable source for living species [4].

30.3.1.1 Exogenously Produced Trans Fat

Saturated fats are usually produced via hydrogenation of liquid *cis*-unsaturated fats, such as vegetable oils in food production, because saturated fats can provide desirable physical properties, for example melting at a convenient temperature (30–40 °C) and high oxidative stability. If hydrogenation is complete, a saturated fatty acid is formed; otherwise, partial hydrogenation of the unsaturated fats converts some of the *cis* double bonds into *trans* double bonds through isomerization in the presence of a catalyst.

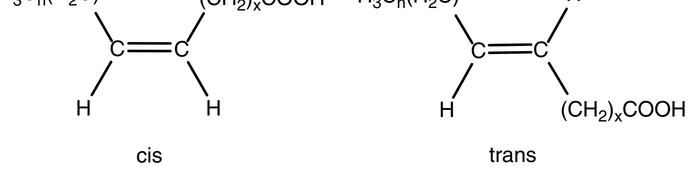


Figure 30.1 Structure of *cis* and *trans* configurations.

This hydrogenation process, first described by French chemist Paul Sabatier in the late 1890s, uses a nickel catalyst to hydrogenate – or saturate – double bonds in vegetable oils. The most abundant *trans* fatty acid in commercial *trans* fat is elaidic acid (18:1 *trans*-9) that is converted from oleic acid by partial hydrogenation. In addition, 18:2, 18:3 and 16:1 fatty acid moieties can also be found in a *trans* configuration in commercial food products [5]. A little *trans* fat is generated naturally in vegetable oils during purification. Trace amounts of *trans* fat are also generated during the process used to deodorize or refine vegetable oils [6].

30.3.1.2 Endogenously Produced Trans Fat

For many years, *trans* fatty acids in living systems have been mostly considered to originate from exogenous food sources. Unsaturated fatty acids naturally occur in the *cis* configuration, although the *trans* form is more stable. A small amount of naturally occurring *trans* fatty acids, which are produced by microorganisms in the ruminant stomach, can be found in meat and dairy products [7]. However, recent studies have shown that exogenous sources cannot account for the total *trans* fatty acids in living species, and *trans* fatty acids could be induced by radical stress in the cell membranes [8].

Cis configurations of unsaturated fatty acids based on phospholipids in the cell membrane are strictly biosynthesized by desaturase enzymes, which are regiospecific and stereoselective. The *trans* fatty acids have been determined in erythrocytes, kidney and heart tissues of young adult rats (4-months-old) fed with a *trans*-fat-free diet [9]. When the rats were treated with CCl_4 under stress conditions, 2% *trans*-fatty acids in plasma lipids were observed, compared with 0.5% in the control groups. In addition, it was found that a significant amount of *trans* fatty acids accumulated in 30-month-old rats due to continuous exposure of cellular components to increasing radicals during aging [4]. Compared to prokaryotic cells, eukaryotic cells show an irreversible, free-radical-induced geometric isomerism.

30.3.1.3 Exogenously vs Endogenously Ptoduced Trans Fat

The concentration of *trans* fats in partially hydrogenated fat is as high as 40% in some shortenings [6], compared with only 6% endogenously derived fats [10]. Since small amounts of *trans* fats are present in natural sources, it is impossible to completely eliminate them from the diet, even if commercial hydrogenation ceases.

The average consumption of commercially produced *trans* fats in the United States is 2–3% of total calories consumed (about 5.8 gram per day) before 2006 [11]. *Trans* fats are abundant in deep-fried foods, bakery products, packaged snack foods, margarines and crackers. However, naturally occurring *trans* fats are consumed in a smaller amount (about 0.5% of total energy intake) from meats and dairy products. The major *trans*-fat isomers are C18:1 *trans*-geometrical isomer, which accounts for about 80~90% of intake *trans* fats [12].

30.3.2 Safety Issues of Trans Fat

Partially hydrogenated oils containing high amount of *trans* fats have been widely used in commercial food products and the safety issue has attracted a lot of attention because consumption of *trans* fats can be related to various diseases. Generally, the lower the number of double bonds, the higher the rigidity of lipid packing. The *trans* isomers are similar to saturated lipids in physical properties. As the main component in the membrane, phospholipids occurring as the *trans* isomers would enhance the rigidity of the membrane and attenuate permeability, and consequently may induce cell dysfunction or death [13].

30.3.2.1 Trans Fat and Cardiovascular Disease

Risk factors of cardiovascular disease such as hypertension, obesity and diabetes are still rising. Therefore, cardiovascular disease is still the main cause of death in the United States. Diet is a significant modulator of these risk factors and the association between *trans* fat in food and coronary heart disease (CHD) has been consistently shown in epidemiologic studies. Based on a 16-year follow-up study among 84 204 women, the risk of CHD can be reduced by 53% (95% CI: 34 to 67; $p < 0.001$) by replacing the 2% *trans* fat intake with *cis* unsaturated fat [14]. In a meta-analysis of four prospective cohort studies, a 23% increase in the incidence of CHD was associated with a 2% increase in energy intake from *trans* fats [3]. Strong positive associations were observed between 25-year death rates from CHD and intake of the *trans* fat elaidic acid ($r = 0.78$, $p < 0.001$) [15].

More experimental studies showed that *trans* fat, especially elaidic acid, has adverse effects on serum lipids by raising levels of low-density lipoprotein (LDL) cholesterol and very low-density lipoprotein (VLDL) cholesterol, reducing levels of high-density lipoprotein (HDL) cholesterol, and increasing the ratio of total cholesterol to HDL cholesterol, all of which are risk factors for CHD [16]. In addition, plasma activity of cholesteryl ester transfer protein (CETP), the main enzyme for transfer of cholesterol esters from HDL to LDL and VLDL, increased with a higher intake of *trans* fats [17]. Through comparison with the intake of other fats, *trans* fats also increase the blood levels of triacylglycerols, increase levels of Lp(a) lipoprotein, and reduce the particle size of LDL cholesterol [18], each of which may further raise the risk of CHD.

30.3.2.2 Trans fat and Systemic Inflammation

A large intake of *trans* fats is positively associated with increased biomarkers of systemic inflammation in women, especially in those with higher body mass index, and the level of interleukin-6 (IL-6) and C-reactive protein (CRP) is increased [19]. Lopez-Garcia and his colleagues suggested CRP levels were 73% higher and IL-6 levels were 17% higher among those with the highest *trans* fat intake compared to people with the lowest consumption [20]. Based on a 16-week double-blind parallel intervention study, TNFα increased by 12% (95% CI: 5–20; $p = 0.002$) in the *trans* fat intake group compared with the control group [21]. The levels of plasma-soluble TNF receptors 1 and 2 were also increased. These results also indicate that the TNFα system may be involved in the development of cardiovascular disease through consumption of *trans* fats.

30.3.2.3 Trans Fat and Alzheimer's Disease

Alzheimer's disease (AD), which causes one of the greatest threats to the future healthcare system, is a degenerative and terminal disease with no current cure. The causes and progression of AD are still not clear, but sufficient numbers of plaques and tangles in the brain are considered to indicate AD. Limited data are available on the potential effect of *trans* fats on the risk of Alzheimer's disease. Morris and coworkers observed a strong increased risk of AD with consumption of both saturated fats and *trans* unsaturated fats in their study [22]. The impact of *trans* fats was tested on an animal model, and the results indicated that intake of *trans* fats modulated brain fatty acid profiles, but had no significant association with risk of AD [23].

30.3.2.4 Trans Fat and Type 2 Diabetes

Type 2 (noninsulin-dependent) diabetes mellitus is increasing rapidly worldwide, and whether *trans* fat intake is a risk factor for type II diabetes has also been investigated. Based on a 16-year follow-up study among 84 204 women, higher intake of *trans* fats was positively associated with higher risk of type 2 diabetes. A 2% increase in energy from *trans* fats was associated with a 39% (95% CI: 1.15–1.67; $p < 0.001$) increase in diabetes risk [24].

30.3.2.5 Trans Fat and Cancer

The results from the French part of the European Prospective Investigation into Cancer and Nutrition suggested that a high serum level of *trans* fats is associated with a high risk of invasive breast cancer in women, based on an average of 7 years of follow-up among 19 934 women [25]. To date, a scientific consensus has not been reached on whether intake of *trans* fats may significantly affect risk of cancer. A relationship between *trans* fats and prostate cancer has been reported, but the results were conflicting, depending on different *trans* fat isomers and research methods.

30.3.2.6 Trans Fat and Other Diseases

Excessive food energy intake is a major factor in obesity, particularly fast food high in *trans* fats. Experiments on an animal model over 6 years showed that a higher intake of *trans* fats resulted in a 7.2% gain in body weight in monkeys, compared with 1.8% gain in a group consuming of *cis* unsaturated fat [26]. In a study based on more than 16 000 men over a 9-year duration, a 2% increase in *trans* fat intake caused a 2.7 cm increase in abdominal circumference ($p < 0.001$) [27]. Similar results were obtained in another study based on more than 41 000 women over an 8-year duration, showing that the increase in *trans* fat consumption was associated with the increase in body weight [28].

Nonalcoholic fatty liver disease (NAFLD) is recognized as the leading cause of chronic liver disease in adults and children, of which the most worrisome form is nonalcoholic steatohepatitis (NASH). Tetri and colleagues showed that a high *trans* fat diet caused NASH in sedentary mice [29].

30.3.3 Regulation of Trans Fats Worldwide

Many countries or local governments have introduced corresponding regulations on *trans* fats, particularly for partially hydrogenated oil production, because of the health problems. In 2003, the World Health Organization (WHO) and the Food and Agriculture Organization (FAO) of the United Nations recommended that less than 1% of dietary energy intake should come from consuming *trans* fats.

30.3.3.1 Trans Fat Regulation in the United States

The Food and Drug Administration (FDA) in the United States issued a regulation on 11 July 2003, requiring manufacturers to list the *trans* fat amount as an individual item on the nutrition facts panel of foods and some dietary supplements, which became effective on 1 January 2006. But there remain some problems about the limitation, as *trans* fat levels of less than 0.5 g per serving can be listed as 0 g *trans*-fat on the food label and it does not cover foods supplied by restaurants. On 5 December 2006, The New York City's Board of Health voted to ban *trans* fats in restaurant food. New York became the first large US city to strictly limit *trans* fats in restaurants. In the 8 November 2013 issue of the Federal Register, the FDA announced a preliminary ruling that *trans* fats are not Generally Recognized As Safe (GRAS) for any use in food [11].

Some associations in the US have taken on responsibility for reducing the consumption of *trans* fat. In 2007, the American Public Health Association adopted a new policy to limit *trans* fat consumption, entitled *Restricting Trans Fatty Acids in the Food Supply*. These guidelines recommended government-required nutrition facts labeling of *trans* fat on all commercial food products, and that federal, state and local governments should ban and monitor the use of *trans* fat in restaurants. Furthermore, public facilities, including universities, prisons and daycare facilities, should stop sale and consumption of foods containing significant amounts of *trans* fats.

In May 2005, Tiburon, California, became the first American city where all restaurants voluntarily cooked with *trans*-fat-free oils. The first county in the nation to restrict *trans* fats was Montgomery County, Maryland, where a ban on *trans* fat in foods from restaurants, supermarket bakeries and delis has been in place since May 2007. Other cities, such as Chicago and Boston and King County in Washington, passed a ban on *trans*-fat use in restaurants. On 25 July 2008, California became the first state to ban *trans* fats in restaurants effective from 1 January 2010.

Based on a thorough review of the scientific evidence, the US FDA finalized its determination in 16 June 2015 that partially hydrogenated oils are not "generally recognized as safe" for use in food.

30.3.3.2 Trans Fat Regulation in China

Since 2003, the Nutrition and Food Institute has been monitoring the *trans* fats in food in China. The preliminary data showed that the average consumption of *trans* fat was about 0.6 g per day at that time, which was much lower than that in Europe and the United States [30]. *Dietary Guidelines for Chinese Residents* published by the Ministry of Health of P. R. China (MOH) in 2007, suggested that the average consumption of edible oil should be no more than 25 g per day, and the total intake of fat should be less than 30% of total calories. It also recommended that residents should keep away from *trans* fats and reduce the intake of food high in partially hydrogenated oil. In December 2007, the MOH adopted a policy entitled *Standards for Nutrition and Food Labeling Management*. This policy demonstrated how *trans* fat should be labeled: products with less than 3% *trans* fat could be labeled as "zero *trans* fat" "none" or "*trans*-fat-free." On 12 October 2011, the amount of *trans* fat and other nutritional information was required to be marked on the labels of prepackaged food, according to the first national standard for food nutrition in China. The labeling took effect on 1 January 2013 [31]. The new regulation also stipulated that if any hydrogenated or partially hydrogenated fat was used to produce the food, the level of *trans* fats should be highlighted on the nutrition information label. It also recommended that the intake of *trans* fats should be less than 2.2 g per day (1% of total calories) because of its positive association with a high risk of cardiovascular disease.

30.3.3.3 Trans Fat Regulation in Taiwan

Although the plasma concentrations of *trans* fats for both male and female adults in Taiwan are 0.4%, lower than those in the US, Japan and other countries [32], cardiovascular disease and cerebrovascular disease are still ranked the second and third leading causes of death in Taiwan. The government has issued an important regulation to manage *trans* fats in Taiwan. Since 1 January 2008, all packaged foods are required to list the amount of *trans* fats on the nutrition facts panel. The regulation defines trans fats as total nonconjugated *trans* fats from partial hydrogenation of edible oils. In addition, this regulation also indicates that *trans* fat levels less than 0.3 g per 100 mL of liquid or 100 g of solid (semi-solid) food products can be listed as 0 g on the nutrition facts panel.

Trans fats can also be generated during the deodorization of vegetable oils such as soybean oil. However, in 2008, the regulation regarding labeling *trans* fats on the nutrition facts panel was only applicable to partially hydrogenated oil. Since the adverse effects to human health caused by *trans* fats from partially hydrogenated oil are the same as those from oil deodorization process, on 15 April 2015, the regulation was amended and redefined *trans* fats as thetotal nonconjugated *trans* fats in food products. Therefore, nonconjugated *trans* fats from either deodorization or partial hydrogenation are now required to be listed on the nutrition facts panel. Thus, oil refineries must modify the conditions of the deodorization process to reduce the amounts of trans fats produced. This regulation also indicates that only when total fats are less than 1 g or *trans* fats are less than 0.3 g per 100 mL of liquid or 100 g of solid (semi-solid) food products, can *trans* fats be expressed as 0 g on the nutrition facts panel. This regulation became effective from 1 July 2015 (according to the manufacturing date) [33].

30.3.4 The Effectiveness of Policies for Reducing Dietary Trans Fat

In 2009, the WHO called for the elimination of *trans* fats from the global food supply. All policy interventions were associated with a reduction in the availability of *trans* fat. National bans virtually eliminated *trans* fat from the food supply and local bans were very successful in removing *trans* fat from fried foods.

The consumption of *trans* fat per resident per day has decreased under the regulations adopted by the United States from 8.0 g per day in 1983 [34] to 2.6 g per day in 2010 [11].

30.4 3-Chloro-1,2-Propanediol and Glycidol Fatty Acid Esters

Chloropropanol (CP) esters are a group of food contaminants induced during food processing. There are several different isomers, such as 2-chloro-1,3-propanediol (2-MCPD) esters, 3-chloro-1,2-propanediol (3-MCPD) esters and 1,3-di-chloropropanols (1,3-DCP) esters (Figure 30.2).

Due to their capability for interconversion, glycidol esters are often grouped with MCPD esters [35]. Fatty acid esters of 3-MCPD and glycidol have attracted a lot of attention since they have been reported to be toxic compounds and occur in various types of food products and raw materials, especially in refined vegetable oils [36].

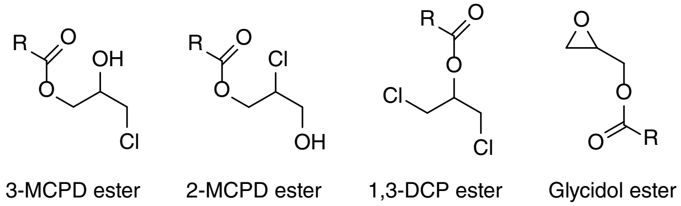


Figure 30.2 Chemical structures of esters of chloropropanols and glycidol.

30.4.1 Formation of 3-MCPD Fatty Acid Esters

Fatty acid esters of 3-MCPD and glycidol are produced during industrial food processing, specifically during deodorization. They are found at high levels in refined vegetable oils and fats, including vegetable oils used in foodstuffs such as cereals, roasted coffee, toasted bread, doughnuts and infant formula [37].

Many studies have focused on the mechanism of formation of 3-MCPD esters, but it is still unclear because the lipid environment makes it difficult to understand.

Various sources of lipid compounds are considered potential precursors for MCPD ester formation in foods, such as glycerol, monoacylglycerols (MAG), diacylglycerols (DAG), triacylglycerols (TAG), phospholipids and glycolipids etc. [38]. Nagy and colleagues demonstrated that the amount of inorganic chlorine, such as $FeCl_3$, $FeCl_2$, $MgCl_2$ and $CaCl_2$, was around the mg/kg level in crude palm oil, and these inorganic chlorine compounds are the originating factors for formation of MCPD esters during edible oil processing. Organic monochlorinated compounds are also available in crude palm oil.

30.4.2 Formation of Glycidol Fatty Acid Esters

Glycidol esters were generated through the thermal treatment of DAG and MAG in an intramolecular rearrangement mechanism, which is independent of MCPD ester formation [39]. At over 200 °C, glycidol esters are predominantly formed by the intramolecular elimination of a fatty acid from DAG, followed by a sequential fatty acid elimination [39].

30.4.3 Safety Issues

Refined oil contains high amounts of 3-MCPD and glycidol esters, and foods using refined oil contain these contaminants as well. None of the direct evidence has shown that 3-MCPD and glycidol esters have adverse health effects on humans, but they are considered toxic owing to the potential to release free 3-MCPD and glycidol during digestion in the gastrointestinal tract [37].

30.4.3.1 Toxicity of 3-MCPD

The European Scientific Committee on Food classified 3-MCPD in 2001 as a nongenotoxic compound and a threshold carcinogen with a tolerable daily intake of 2 μg/kg body weight per day [40]. It is considered to be carcinogenic to rodents via a nongenotoxic mechanism, inducing tumors in males in the testes, mammary glands and the preputial gland, as well as kidney tumors in both genders [41]. Evaluation of the genotoxic potential of 3-MCPD showed that 3-MCPD was not a genotoxic compound *in vivo* in the target organs (kidney and testes) or in nontarget tissue (blood leukocytes, liver and bone marrow) [42].

Mutagenicity of 3-MCPD was observed in *Salmonella typhimurium* in the absence of essential metabolic activation [43]. 3-MCPD was mutagenic in certain assays such as the yeast test [44], the mammalian sister chromatid exchange assay [44] and the mouse lymphoma assay [45]. There was consistency found for *in vitro* mutagenicity, but there has been not enough evidence *in vivo*. Robjohns and colleagues conducted two mutagenicity studies of 3-MCPD *in vivo*, namely a bone marrow micronucleus test in rats and unscheduled DNA synthesis in a rat liver. The results showed that 3-MCPD didn't possess genotoxic activity *in vivo* in the tissues examined [41].

The antifertility effects of 3-MCPD were reported in 1970 by Ericsson and Baker [46]. Loss of fertility was observed in male rats in less than a week by daily oral or subcutaneous administration of 3-MCPD. Interestingly, fertility returned within one week after treatment. There were distinguishing differences in uterine and oviducal sperm numbers, morphology and motility between treated and control groups. 3-MCPD might be used as a rat chemosterilant [47].

30.4.3.2 Toxicity of Glycidol

Glycidol is classified as a genotoxic carcinogen by the IARC and an *as low as reasonably achievable* principle should be applied [48]. Glycidol directly acts as a mutagen and a carcinogen in rodents, but there are no epidemiological or clinical studies of glycidol in humans [37].

In the National Toxicology Program (NTP) carcinogenicity study, F344/N rats and B6C3F1 mice were administered glycidol by gavage. The results showed that high doses of glycidol caused early death [49]. Survival of rats that received glycidol was markedly reduced compared with the control.

Glycidol was found to be mutagenic in a variety of *in vitro* and *in vivo* genotoxicity tests. The result of bacterial mutagenicity was positive, in the presence or absence of a metabolic activation system [49]. *In vitro*, glycidol exhibited great mutagenic activity in various assays in mammalian cells, such as the *Salmonella*/mammalian microsome assay, the L5178Y mouse lymphoma assay, and unscheduled DNA synthesis [50]. Glycidol can also induce gene mutation, chromosomal aberration and sister chromatid exchange [51]. *In vivo*, when B6C3F1 mice were administered glycidol via intraperitoneal injection, micronuclei were induced in the bone marrow. It also induced sex-linked recessive mutations in fruit flies.

Glycidol was positively associated with neoplastic diseases. In a 2-year study of gavage feeding of glycidol, Fischer-344 rats and B6C3F1 mice were examined for carcinogenicity. The incidences in the neoplasms of Harderian gland in males and females, the forestomach in males and the mammary gland in females increased with high doses of glycidol [52].

30.5 Safety Issues of Fat-Soluble Components and Contaminants

30.5.1 Cholesterol and Cholesterol Oxides

Cholesterol is a sterol, which is the essential structural component of animal cell membranes. It is the main steroid for mammals and occurs in its free form or esterified with saturated and unsaturated fatty acids.

Cholesterol oxides are a group of sterols containing an additional functional group, which are commonly found in food with high cholesterol content, such as meat, egg yolk and full fat dairy products [53]. They are generated during food processing such as heating, freeze-drying and deep-frying [54]. Some cholesterol oxides are produced endogenously *in vivo* by enzymatic or nonenzymatic cholesterol oxidation [53].

Cholesterol oxides are fat soluble compounds that are readily absorbed into the blood stream from dietary sources, then transported via low density lipoprotein (LDL) cholesterol to the liver. They are regarded as risk factors for atherosclerotic disease [53]. A positive association was found between high intake of cholesterol oxides in Indian ghee (12.3% of the total cholesterol content) and an increased risk of arteriosclerosis observed in Indian immigrant populations [55]. The concentration of 7β-hydroxycholesterol in serum is considered the biomarker of rapid progression of carotid arteriosclerosis in humans [56]. Some researchers have shown that endothelial cells [57], smooth muscle cells [58] and fibroblasts [59] can be damaged by excess amounts of cholesterol oxides. All of these cells are major components of the arterial wall. Cholesterol oxides can induce atherosclerotic disease, as evidenced by many studies.

Cholesterol oxides have been reported as having proinflammatory effects as they are able to modulate the synthesis of cytokines, growth factors and adhesion molecules [60]. The level of basic fibroblast growth factor (bFGF), a cytokine with mitogenic and fibrogenic activities, increased when smooth muscle cells were treated with 25-hydroxycholesterol [61].

Cholesterol oxides play an important role in the pathobiology of type 2 diabetes [53]. Dyer and colleagues determined the level of 7-ketocholesterol in normal and type 2 diabetic patients. The results showed lower levels of 7-ketocholesterol in nondiabetic vascular patients than in controls [62]. A similar result was demonstrated by other studies, in which the level of plasma 7-ketocholesterol in diabetic patients was significantly higher than in controls [63].

30.5.2 Polychlorinated Biphenyls (PCBs)

PCBs are a group of chemicals with two connected benzene rings and 1–10 chlorine atoms. PCBs are considered ubiquitous contaminants, which were once widely used as plasticizers, organic diluents, dielectric and coolant fluids, and so on. The manufacture and use of PCBs has been banned in many countries since the late 1970s. They accumulate through the food chain and it takes a long time for highly chlorinated PCB congeners to break down naturally. More than 90% of nonoccupational exposure to PCBs is food consumption, particularly fish, meat and dairy products [64].

PCBs have been demonstrated to cause a variety of adverse health effects to humans. In 1968 and 1979, people with massive PCB poisoning were found in Fukuoka, Japan and central Taiwan due to PCB-contaminated rice bran oil. PCBs were used as a heating medium during deodorization of rice bran oil. The rice bran oil was contaminated by PCBs due to leakage of a heating coil tube in the deodorization chamber. There were 1655 poisoned patients found in Japan and the average concentration of PCBs in their blood was below 10 ppb, whereas normally it is below 2 ppb. A similar, but more serious, mass outbreak also occurred in Taiwan. There were 2025 poisoned patients and the average PCB concentration in their blood was 51.1 ppb. The highest PCB level found in these patients was 90 ppb [65].

The general symptoms in people with PCB poisoning include swelling of the eyelids, blackening of the nails, brown pigmentation of the skin and growth of pimples, blackheads and severe acne. There are two ways of transmitting PCBs to infants either via the placenta or by breastfeeding. Poisoned pregnant women will give birth to infants with black pigmented skin and a compromised immune system, which are also commonly known as "Cola-colored babies" or "Yucheng children." Several decades after the initial poisoning, the victims will still have body ulceration and blistering, as well as hormonal or immune system disorders. Considering the potency of such poisons, excess exposure to PCBs still makes people shudder. PCBs are widely used in capacitors, transformers, heating media and in a variety of industrial uses. Thus, it is widely present in the environment and does not easily break down. In order to avoid its contamination of foods, PCB levels in various foods are set strict limits of between 0.2 and 1 ppm in Taiwan. Similarly, there is a 5.0 ppm limit for PCBs in paper used as food packaging material.

The carcinogenicity of PCBs has been confirmed in animal experiments. When rats were fed with PCBs over approximately 21 months, 14% (26/184) hepatocellular carcinomas and 78% (144/184) neoplastic nodules in the liver of rats were found, whereas only 0.58% (1/173) and 0% (0/173) were seen in the control group [66]. In another 2-year PCB feeding study, hepatocellular trabecular carcinoma, adenocarcinoma and neoplastic nodules were observed in Sprague–Dawley rats. In addition, females were found to be more susceptible to PCB-induced hepatocellular neoplasms than males [67].

Health risks to humans via dietary intake of seafood were assessed, with the results showing that exposure to PCBs in fish was not a health risk factor [68]. However, the relationship between estimated consumption of PCBs and potential human health effects remains controversial. It was found that consumption of fish contaminated with PCBs during pregnancy was associated with lower birth weights and it continued to affect growth through breast feeding [69]. Another study found dietary PCB exposure was associated with impairments in memory and learning in older adults, whereas executive and visual–spatial functions were unaffected [70]. Epidemiological studies suggested that no other acute or chronic health effects were related to PCB exposure, except skin and eye irritation [71].

30.5.3 Polyaromatic Hydrocarbons (PAHs)

PAHs are composed of more than three linearly or angularly fused benzene rings, which contain only carbon and hydrogen. They are generated during incomplete combustion of organic materials, such as fossil fuels and tar deposits. PAHs can be found in uncooked foods such as fish, vegetables and cereals, and can also be formed during cooking processes, such as meats cooked at high temperatures over an open flame [72]. Diet is considered to be the major source of human exposure to PAHs, which are highly lipid-soluble compounds and are easily absorbed through the gastrointestinal tract [73]. PAHs will be produced in foods during heating, drying and smoking processes. PAHs may be generated in edible oils such as oilseeds (e.g., rapeseed, coconut kernels) during the drying process prior to oil extraction. In an effort to determine 14 kinds of PAHs in 20 edible oil samples, Hsu *et al.* [74] found that 16 samples contained PAHs; fortunately their contents were in the range 0.2 to 0.73 μg/kg, which is far below the EU limit of 2.0 μg/kg.

Many PAHs are highly toxic, mutagenic and/or carcinogenic. The toxicity is structure-dependent and ranges from being nontoxic to extremely toxic. Consumption of PAHs in the diet can cause tumors in rodents at multiple sites [75], particularly in the upper gastrointestinal tract. It has also been demonstrated that benzo[a]pyrene causes mammary gland tumors in female rats [76].

Results of epidemiological studies have revealed dietary exposure to PAHs is associated with the risk of breast cancer [77], gastric cancer [78] and colon cancer [79] in humans. In addition, benzo[a]pyrene-DNA adducts, which are indicators of carcinogenesis, have been obtained in human colon and gastric tissue [80]. It has been demonstrated that PAHs can bind covalently to cellular macromolecules such as DNA and protein, inducing errors in DNA replication and mutations, further inducing carcinogenesis [80].

High prenatal exposure to airborne PAHs is associated with a lower IQ index at age 3 (95% CI: −9.05 to −2.33; $p < 0.01$ [81]. The result is consistent with findings in Poland. Prenatal exposure to PAHs adversely affects children's cognitive development by 5 years old, corresponding to an estimated average decrease of 3.8 IQ points [82].

In addition, it is thought that occupational exposure to PAHs has an adverse effect on human health, such as increased risk of cerebrovascular disease and arteriosclerosis. It has been suggested that the lung seems to be the major target organ for PAHs, and increased risk of lung cancer has been found in response to high exposure to them [83]. An increased risk of skin cancer is associated with high dermal exposure to PAHs [84]. High exposure to PAHs from the coal tar and pitch industry is also highly related to bladder cancer [85].

30.5.4 Heterocyclic Amines (HCAs)

Heterocyclic amines (HCAs) are a group of compounds containing at least one heterocyclic ring, which are generated during high temperature cooking of protein-rich food such as meat and fish. Creatinine, sugar and amino acids in food are the precursors of HCAs [86]. The content of HCAs in foods increases with heating temperature and time [87].

HCAs are considered mutagenic and carcinogenic compounds. For example, they are mutagenic to cultured Chinese hamster lung cells [88]. The carcinogenicity of HCAs has been demonstrated in long-term animal feeding experiments. It was reported that tumors were found in the liver, lung, blood vessels and hematopoietic system [89] in mice with administration of 100–800 ppm of HCAs. HCAs, which can be formed from tryptophan pyrolyzing, are hepatic carcinogens to mice. PhIP (2-amino-1-methyl-6-phenylimidazo[4,5-b]pyridine), the most abundant HCA in cooked food, causes carcinomas in the prostate of the male rat [90].

The relationship between intake of HCAs and risk of cancer in humans remains controversial. In a case-control study in Uruguay, a positive association was found between increasing intake of estimated HCAs in meat and risk of human breast cancer (ratio = 3.34, 95% CI = 1.85–6.02) [91]. In other studies, the results showed that dietary exposure to HCAs was unlikely to increase the incidence of cancer in the colon [91], rectum, bladder or kidney [92]. Comparison of the carcinogenic dose in rodents ($TD_{50} = 0.1\sim64.6$ mg/kg/day, depending on different HCA congeners) and the actual human daily intake of estimated HCAs suggested that levels of HCAs in the diet were definitely too low for carcinogenesis [92].

References

1 Belitz, H. D., Grosch, W., Schieberle, P., *Food Chemistry*. Third ed, 2004, Springer, Berlin, Germany.

2 Vafeiadou, K., Weech, M., Sharma, V., Yaqoob, P., Todd, S., Williams, C. M., Jackson, K. G., Lovegrove, J. A., A review of the evidence for the effects of total dietary fat, saturated, monounsaturated and n-6 polyunsaturated fatty acids on vascular function, endothelial progenitor cells and microparticles. *British Journal of Nutrition* 2012, 107, 303–324.

3 Mozaffarian, D., Katan, M. B., Ascherio, A., Stampfer, M. J., Willett, W. C., Trans fatty acids and cardiovascular disease. *New England Journal of Medicine* 2006, 354, 1601–1613.

4 Zambonin, L., Prata, C., Cabrini, L., Maraldi, T., Fiorentini, D., Dalla Sega, F. V., Hakim, G., Landi, L., Effect of radical stress and ageing on the occurrence of trans fatty acids in rats fed a trans-free diet. *Free Radical Biology and Medicine* 2008, 44, 594–601.

5 Weggemans, R. M., Rudrum, M., Trautwein, E. A., Intake of ruminant versus industrial trans fatty acids and risk of coronary heart disease: What is the evidence? *European Journal of Lipid Science and Technology* 2004, 106, 390–397.

6 Remig, V., Franklin, B., Margolis, S., Kostas, G., Nece, T., Street, J. C., Trans fats in America: a review of their use, consumption, health implications, and regulation. *Journal of the American Dietetic Association* 2010, 110, 585–592.

7 Schwarz, W., Trans unsaturated fatty acids in European nutrition. *European Journal of Lipid Science and Technology* 2000, 102, 633–635.

8 Ferreri, C., Kratzsch, S., Brede, O., Marciniak, B., Chatgilialoglu, C., Trans lipid formation induced by thiols in human monocytic leukemia cells. *Free Radical Biology and Medicine* 2005, 38, 1180–1187.

9 Zambonin, L., Ferreri, C., Cabrini, L., Prata, C., Chatgilialoglu, C., Landi, L., Occurrence of trans fatty acids in rats fed a trans-free diet: a free radical-mediated formation? *Free Radical Biology and Medicine* 2006, 40, 1549–1556.

10 Kepler, C. R., Hirons, K. P., McNeill, J., Tove, S., Intermediates and products of the biohydrogenation of linoleic acid by Butyrivibrio fibrisolvens. *Journal of Biological Chemistry* 1966, 241, 1350–1354.

11 Department of Food Administration, Tentative determination regarding partially hydrogenated oils; request for comments and for scientific data and information. *Federal Register* 2013, 78, 67169–67175.

12 Allison, D. B., Egan, S. K., Barraj, L. M., Caughman, C., Infante, M., Heimbach, J. T., Estimated intakes of trans fatty and other fatty acids in the US population. *Journal of the American Dietetic Association* 1999, 99, 166–174.

13 Roach, C., Feller, S. E., Ward, J. A., Shaikh, S. R., Zerouga, M., Stillwell, W., Comparison of cis and trans fatty acid containing phosphatidylcholines on membrane properties. *Biochemistry* 2004, 43, 6344–6351.

14 Hu, F. B., Stampfer, M. J., Manson, J. E., Rimm, E., Colditz, G. A., Rosner, B. A., Hennekens, C. H., Willett, W. C., Dietary fat intake and the risk of coronary heart disease in women. *New England Journal of Medicine* 1997, 337, 1491–1499.

15 Kromhout, D., Menotti, A., Bloemberg, B., Aravanis, C., Blackburn, H., Buzina, R., Dontas, A. S., Fidanza, F., Giaipaoli, S., Jansen, A., Karvonen, M., Katan, M., Nissinen, A., Nedeljkovic, S., Pekkanen, J., Pekkarinen, M., Punsar, S., Rasanen, L., Simic, B., Toshima, H., Dietary saturated and trans fatty acids and cholesterol and 25-year

mortality from coronary heart disease: The Seven Countries Study. *Preventive Medicine* 1995, 24, 308–315.

16 Mensink, R. P., Katan, M. B., Effect of dietary trans fatty acids on high-density and low-density lipoprotein cholesterol levels in healthy subjects. *New England Journal of Medicine* 1990, 323, 439–445.

17 van Tol, A., Zock, P. L., van Gent, T., Scheek, L. M., Katan, M. B., Dietary trans fatty acids increase serum cholesterylester transfer protein activity in man. *Atherosclerosis* 1995, 115, 129–134.

18 Mauger, J.-F., Lichtenstein, A. H., Ausman, L. M., Jalbert, S. M., Jauhiainen, M., Ehnholm, C., Lamarche, B., Effect of different forms of dietary hydrogenated fats on LDL particle size. *The American Journal of Clinical Nutrition* 2003, 78, 370–375.

19 Mozaffarian, D., Pischon, T., Hankinson, S. E., Rifai, N., Joshipura, K., Willett, W. C., Rimm, E. B., Dietary intake of trans fatty acids and systemic inflammation in women. *The American Journal of Clinical Nutrition* 2004, 79, 606–612.

20 Lopez-Garcia, E., Schulze, M. B., Meigs, J. B., Manson, J. E., Rifai, N., Stampfer, M. J., Willett, W. C., Hu, F. B., Consumption of trans fatty acids is related to plasma biomarkers of inflammation and endothelial dysfunction. *The Journal of Nutrition* 2005, 135, 562–566.

21 Bendsen, N. T., Stender, S., Szecsi, P. B., Pedersen, S. B., Basu, S., Hellgren, L. I., Newman, J. W., Larsen, T. M., Haugaard, S. B., Astrup, A., Effect of industrially produced trans fat on markers of systemic inflammation: evidence from a randomized trial in women. *Journal of Lipid Research* 2011, 52, 1821–1828.

22 Morris, M. C., Evans, D. A., Bienias, J. L., Tangney, C. C., Bennett, D. A., Aggarwal, N., Schneider, J., Wilson, R. S., Dietary fats and the risk of incident Alzheimer disease. *Archives of Neurology* 2003, 60, 194–200.

23 Phivilay, A., Julien, C., Tremblay, C., Berthiaume, L., Julien, P., Giguere, Y., Calon, F., High dietary consumption of trans fatty acids decreases brain docosahexaenoic acid but does not alter amyloid-β and tau pathologies in the 3xTg-AD model of Alzheimer's disease. *Neuroscience* 2009, 159, 296–307.

24 Salmeron, J., Hu, F. B., Manson, J. E., Stampfer, M. J., Colditz, G. A., Rimm, E. B., Willett, W. C., Dietary fat intake and risk of type 2 diabetes in women. *The American Journal of Clinical Nutrition* 2001, 73, 1019–1026.

25 Chajès, V., Thiébaut, A. C., Rotival, M., Gauthier, E., Maillard, V., Boutron-Ruault, M.-C., Joulin, V., Lenoir, G. M., Clavel-Chapelon, F., Association between serum trans-monounsaturated fatty acids and breast cancer risk in the E3N-EPIC Study. *American Journal of epidemiology* 2008, 167, 1312–1320.

26 Kavanagh, K., Jones, K. L., Sawyer, J., Kelley, K., Carr, J. J., Wagner, J. D., Rudel, L. L., Trans fat diet induces abdominal obesity and changes in insulin sensitivity in monkeys. *Obesity* 2007, 15, 1675–1684.

27 Koh-Banerjee, P., Chu, N.-F., Spiegelman, D., Rosner, B., Colditz, G., Willett, W., Rimm, E., Prospective study of the association of changes in dietary intake, physical activity, alcohol consumption, and smoking with 9-y gain in waist circumference among 16 587 US men. *The American Journal of Clinical Nutrition* 2003, 78, 719–727.

28 Field, A. E., Willett, W. C., Lissner, L., Colditz, G. A., Dietary fat and weight gain among women in the Nurses' Health Study. *Obesity* 2007, 15, 967–976.

29 Tiniakos, D. G., Vos, M. B., Brunt, E. M., Nonalcoholic fatty liver disease: pathology and pathogenesis. *Annual Review of Pathological Mechanical Disease* 2010, 5, 145–171.

30 “Chinese residents dietary intake of trans fatty acid levels and risk assessment”, 2013, http://news.xinhuanet.com/food/2013-07/09/c_124982399.htm (accessed November 2016) [in Chinese].

31 National standard for trans fat labeling. http://www.chinadaily.com.cn/cndy/2011-11/04/content_14034750.htm (accessed November 2016).

32 Su, H. M., Hsieh, Y. T., Pan, W. H., Comparison of plasma trans-fatty acid, docosahexaenoic acid and palmitoleic acid levels with respect to gender, age and area of residence in adult Taiwanese. *Nutrition Science Journal* 2014, 39, 1–10.

33 Taiwan Food and Drug Administration Agency, Food Nutrition Labeling Law, 2012, http://consumer.fda.gov.tw/Law/Detail.aspx?nodeID=518&lawid=587 (accessed November 2016) [in Chinese].

34 Tarrago-Trani, M. T., Phillips, K. M., Lemar, L. E., Holden, J. M., New and existing oils and fats used in products with reduced trans-fatty acid content. *Journal of the American Dietetic Association* 2006, 106, 867–880.

35 Kaze, N., Sato, H., Yamamoto, H., Watanabe, Y., Bidirectional conversion between 3-monochloro-1,2-propanediol and glycidol in course of the procedure of DGF standard methods. *Journal of the American Oil Chemists Society* 2011, 88, 1143–1151.

36 Kuhlmann, J., Determination of bound 2, 3-epoxy-1-propanol (glycidol) and bound monochloropropanediol (MCPD) in refined oils. *European Journal of Lipid Science and Technology* 2011, 113, 335–344.

37 Bakhiya, N., Abraham, K., Gürtler, R., Appel, K. E., Lampen, A., Toxicological assessment of 3-chloropropane-1, 2-diol and glycidol fatty acid esters in food. *Molecular Nutrition and Food Research* 2011, 55, 509–521.

38 Craft, B., Chiodini, A., Garst, J., Granvogl, M., Fatty acid esters of monochloropropanediol (MCPD) and glycidol in refined edible oils. *Food Additives and Contaminants: Part A* 2013, 30, 46–51.

39 Destaillats, F., Craft, B. D., Dubois, M., Nagy, K., Glycidyl esters in refined palm (Elaeis guineensis) oil and related fractions. Part I: Formation mechanism. *Food Chemistry* 2012, 131, 1391–1398.

40 European Commission, Opinion on 3-monochloropropane-1,2-diol (3-MCPD), Updating the SCF opinion of 1994 adopted on 30 May 2001. https://ec.europa.eu/food/sites/food/files/safety/docs/cs_contaminants_catalogue_mcpd_out91_en.pdf (accessed November 2016).

41 Robjohns, S., Marshall, R., Fellows, M., Kowalczyk, G., In vivo genotoxicity studies with 3-monochloropropan-1, 2-diol. *Mutagenesis* 2003, 18, 401–404.

42 El Ramy, R., Elhkim, M. O., Lezmi, S., Poul, J., Evaluation of the genotoxic potential of 3-monochloropropane-1, 2-diol (3-MCPD) and its metabolites, glycidol and β-chlorolactic acid, using the single cell gel/comet assay. *Food and Chemical Toxicology* 2007, 45, 41–48.

43 Zeiger, E., Anderson, B., Haworth, S., Lawlor, T., Mortelmans, K., Salmonella mutagenicity tests: V. Results from the testing of 311 chemicals. *Environmental and Molecular Mutagenesis* 1992, 19, 2–141.

44 Rossi, A., Migliore, L., Lascialfari, D., Sbrana, I., Loprieno, N., Tortoreto, M., Bidoli, F., Pantarotto, C., Genotoxicity, metabolism and blood kinetics of epichlorohydrin in mice. *Mutation Research/Genetic Toxicology* 1983, 118, 213–226.

45 Henderson, L., Bosworth, H., Ransome, S., Banks, S., Brabbs, C., Tinner, A., An assessment of the mutagenic potential of 1, 3-dichloro-2-propanol, 3-chloro-1, 2-proanediol and a cocktail of chloropropanols using the mouse lymohoma TK locuc assay. *Unpublished report No ULR 130 ABC/861423.*

46 Ericsson, R., Baker, V., Male antifertility compounds: biological properties of U-5897 and U-15,646. *Journal of Reproduction and Fertility* 1970, 21, 267–273.

47 Ericsson, R., Male antifertility compounds: U-5897 as a rat chemosterilant. *Journal of Reproduction and Fertility* 1970, 22, 213–222.

48 World Health Organization/International Agency for Research on Cancer. *IARC Monographs on the Cvaluation of Carcinogenic Risks to Humans*. International Agency for Research on Cancer: 2001; Vol. 78.

49 Irwin, R., Toxicology and carcinogenesis studies of glycidol (CAS NO. 556-52-5) in F344/N rats and B6C3F1 mice (gavage studies). In *NIH Publication*, Department of Health and Human Services: 1990; Vol. 90.

50 Thompson, E., Coppinger, W., Piper, C., McCarroll, N., Oberly, T., Robinson, D., Mutagenicity of alkyl glycidyl ethers in three short-term assays. *Mutation Research/ Genetic Toxicology* 1981, 90, 213–231.

51 Norppa, H., Hemminki, K., Sorsa, M., Vainio, H., Effect of monosubstituted epoxides on chromosome aberrations and SCE in cultured human lymphocytes. *Mutation Research Letters* 1981, 91, 243–250.

52 Irwin, R. D., Eustis, S. L., Stefanski, S., Haseman, J. K., Carcinogenicity of glycidol in F344 rats and B6C3F1 mice. *Journal of Applied Toxicology* 1996, 16, 201–209.

53 Brown, A. J., Jessup, W., Oxysterols and atherosclerosis. *Atherosclerosis* 1999, 142, 1–28.

54 Savage, G. P., Dutta, P. C., Rodriguez-Estrada, M. T., Cholesterol oxides: their occurrence and methods to prevent their generation in foods. *Asia Pacific Journal of Clinical Nutrition* 2002, 11, 72–78.

55 Jacobson, M., Cholesterol oxides in Indian ghee: possible cause of unexplained high risk of atherosclerosis in Indian immigrant populations. *The Lancet* 1987, 330, 656–658.

56 Salonen, J. T., Nyysso, K., Salonen, R., Porkkala-Sarataho, E., Tuomainen, T.-P., Diczfalusy, U., Bjo, I., Lipoprotein oxidation and progression of carotid atherosclerosis. *Circulation* 1997, 95, 840–845.

57 Ramasamy, S., Boissonneault, G. A., Hennig, B., Oxysterol-induced endothelial cell dysfunction in culture. *Journal of the American College of Nutrition* 1992, 11, 532–538.

58 Hughes, H., Mathews, B., Lenz, M., Guyton, J., Cytotoxicity of oxidized LDL to porcine aortic smooth muscle cells is associated with the oxysterols 7-ketocholesterol and 7-hydroxycholesterol. *Arteriosclerosis, Thrombosis, and Vascular Biology* 1994, 14, 1177–1185.

59 Fielding, C. J., Bist, A., Fielding, P. E., Caveolin mRNA levels are up-regulated by free cholesterol and down-regulated by oxysterols in fibroblast monolayers. *Proceedings of the National Academy of Sciences* 1997, 94, 3753–3758.

60 Leonarduzzi, G., Sottero, B., Poli, G., Oxidized products of cholesterol: dietary and metabolic origin, and proatherosclerotic effects (review). *The Journal of Nutritional Biochemistry* 2002, 13, 700–710.

61 Kraemer, R., Pomerantz, K., Joseph-Silverstein, J., Hajjar, D., Induction of basic fibroblast growth factor mRNA and protein synthesis in smooth muscle cells by cholesteryl ester enrichment and 25-hydroxycholesterol. *Journal of Biological Chemistry* 1993, 268, 8040–8045.

62 Dyer, R. G., Stewart, M. W., Mitcheson, J., George, K., Alberti, M., Laker, M. F., 7-ketocholesterol, a specific indicator of lipoprotein oxidation, and malondialdehyde in non-insulin dependent diabetes and peripheral vascular disease. *Clinica Chimica Acta* 1997, 260, 1–13.

63 Murakami, H., Tamasawa, N., Matsui, J., Yamato, K., JingZhi, G., Suda, T., Plasma levels of soluble vascular adhesion molecule-1 and cholesterol oxidation product in type 2 diabetic patients with nephropathy. *Journal of Atherosclerosis and Thrombosis* 2001, 8, 21–24.

64 Duarte-Davidson, R., Jones, K., Polychlorinated biphenyls (PCBs) in the UK population: estimated intake, exposure and body burden. *Science of the Total Environment* 1994, 151, 131–152.

65 Environmental Protection Agency, *PCBs Management Manual*. 1993. Taiwan Environmental Agency.

66 Kimbrough, R. D., Squire, R. A., Linder, R. E., Strandberg, J. D., Montali, R. J., Burse, V. W., Induction of liver tumors in Sherman strain female rats by polychlorinated biphenyl Aroclor 1260. *Journal of the National Cancer Institute* 1975, 55, 1453–1459.

67 Norback, D., Weltman, R. H., Polychlorinated biphenyl induction of hepatocellular carcinoma in the Sprague-Dawley rat. *Environmental Health Perspectives* 1985, 60, 97.

68 Storelli, M., Potential human health risks from metals (Hg, Cd, and Pb) and polychlorinated biphenyls (PCBs) via seafood consumption: estimation of target hazard quotients (THQs) and toxic equivalents (TEQs). *Food and Chemical Toxicology* 2008, 46, 2782–2788.

69 Jacobson, J. L., Jacobson, S. W., Humphrey, H. E., Effects of exposure to PCBs and related compounds on growth and activity in children. *Neurotoxicology and Teratology* 1990, 12, 319–326.

70 Schantz, S. L., Gasior, D. M., Polverejan, E., McCaffrey, R. J., Sweeney, A. M., Humphrey, H., Gardiner, J. C., Impairments of memory and learning in older adults exposed to polychlorinated biphenyls via consumption of Great Lakes fish. *Environmental Health Perspectives* 2001, 109, 605.

71 Ross, G., The public health implications of polychlorinated biphenyls (PCBs) in the environment. *Ecotoxicology and Environmental Safety* 2004, 59, 275–291.

72 Finlayson-Pitts, B. J., Pitts, J. N., Tropospheric air pollution: ozone, airborne toxics, polycyclic aromatic hydrocarbons, and particles. *Science* 1997, 276, 1045–1051.

73 Cerniglia, C. E., *Microbial Metabolism of Polycyclic Aromatic Hydrocarbons*. Academic Press: 1984.

74 Hsu, C. L., Wo, B. S., Su, S. C., Shih, D. Y. C., The study on the multiresidue analytical method for determining PAHs in edible oil. *Annual Report of BFDA, Taiwan* 2008, 26, 183–197.

75 Ohgaki, H., Takayama, S., Sugimura, T., Carcinogenicities of heterocyclic amines in cooked food. *Mutation Research/Genetic Toxicology* 1991, 259, 399–410.

76 El-Bayoumy, K., Chae, Y.-H., Upadhyaya, P., Rivenson, A., Kurtzke, C., Reddy, B., Hecht, S. S., Comparative tumorigenicity of benzo [a] pyrene, 1-nitropyrene and 2-amino-1-methyl-6-phenylimidazo [4, 5-b] pyridine administered by gavage to female CD rats. *Carcinogenesis* 1995, 16, 431–434.

77 Xia, Z., Duan, X., Qiu, W., Liu, D., Wang, B., Tao, S., Jiang, Q., Lu, B., Song, Y., Hu, X., Health risk assessment on dietary exposure to polycyclic aromatic hydrocarbons (PAHs) in Taiyuan, China. *Science of the Total Environment* 2010, 408, 5331–5337.

78 Dungal, N., The special problem of stomach cancer in iceland: With particular reference to dietary factors. *JAMA* 1961, 178, 789–798.

79 Sachse, C., Smith, G., Wilkie, M. J., Barrett, J. H., Waxman, R., Sullivan, F., Forman, D., Bishop, D. T., Wolf, C. R., A pharmacogenetic study to investigate the role of dietary carcinogens in the etiology of colorectal cancer. *Carcinogenesis* 2002, 23, 1839–1850.

80 Alexandrov, K., Rojas, M., Kadlubar, F. F., Lang, N. P., Bartsch, H., Evidence of anti-benzo [a] pyrene diolepoxide-DNA adduct formation in human colon mucosa. *Carcinogenesis* 1996, 17, 2081–2083.

81 Perera, F. P., Rauh, V., Whyatt, R. M., Tsai, W.-Y., Tang, D., Diaz, D., Hoepner, L., Barr, D., Tu, Y.-H., Camann, D., Effect of prenatal exposure to airborne polycyclic aromatic hydrocarbons on neurodevelopment in the first 3 years of life among inner-city children. *Environmental Health Perspectives* 2006, 1287–1292.

82 Edwards, S. C., Jedrychowski, W., Butscher, M., Camann, D., Kieltyka, A., Mroz, E., Flak, E., Li, Z., Wang, S., Rauh, V., Prenatal exposure to airborne polycyclic aromatic hydrocarbons and children's intelligence at 5 years of age in a prospective cohort study in Poland. *Environmental Health Perspectives* 2010, 118, 1326–1331.

83 Armstrong, B., Tremblay, C., Baris, D., Thériault, G., Lung cancer mortality and polynuclear aromatic hydrocarbons: a case-cohort study of aluminum production workers in Arvida, Quebec, Canada. *American Journal of Epidemiology* 1994, 139, 250–262.

84 Boffetta, P., Jourenkova, N., Gustavsson, P., Cancer risk from occupational and environmental exposure to polycyclic aromatic hydrocarbons. *Cancer Causes and Control* 1997, 8, 444–472.

85 Tremblay, C., Armstrong, B., Thériault, G., Brodeur, J., Estimation of risk of developing bladder cancer among workers exposed to coal tar pitch volatiles in the primary aluminum industry. *American Journal of Industrial Medicine* 1995, 27, 335–348.

86 Jägerstad, M., Skog, K., Grivas, S., Olsson, K., Formation of heterocyclic amines using model systems. *Mutation Research/Genetic Toxicology* 1991, 259, 219–233.

87 Chen, B. H., Chiu, C. P., Analysis, formation and inhibition of heterocyclic amines in foods: an overview. *Journal of Food and Drug Analysis* 1998, 6, 625–636.

88 Nakayasu, M., Nakasato, F., Sakamoto, H., Terada, M., Sugimura, T., Mutagenic activity of heterocyclic amines in Chinese hamster lung cells with diphtheria toxin resistance as a marker. *Mutation Research/Genetic Toxicology* 1983, 118, 91–102.

89 Ohgaki, H., Hasegawa, H., Suenaga, M., Sato, S., Takayama, S., Sugimura, T., Carcinogenicity in mice of a mutagenic compound, 2-amino-3, 8-dimethylimidazo [4, 5-f] quinoxaline (MeIQx) from cooked foods. *Carcinogenesis* 1987, 8, 665–668.

90 Shirai, T., Sano, M., Tamano, S., Takahashi, S., Hirose, M., Futakuchi, M., Hasegawa, R., Imaida, K., Matsumoto, K.-i., Wakabayashi, K., The prostate: a target for carcinogenicity of 2-amino-1-methyl-6-phenylimidazo [4, 5-b] pyridine (PhIP) derived from cooked foods. *Cancer Research* 1997, 57, 195–198.

91 De Stefani, E., Ronco, A., Mendilaharsu, M., Guidobono, M., Deneo-Pellegrini, H., Meat intake, heterocyclic amines, and risk of breast cancer: a case-control study in Uruguay. *Cancer Epidemiology Biomarkers and Prevention* 1997, 6, 573–581.

92 Augustsson, K., Skog, K., Jägerstad, M., Dickman, P. W., Steineck, G., Dietary heterocyclic amines and cancer of the colon, rectum, bladder, and kidney: a population-based study. *Lancet* 1999, 353, 703–707.

31

Grain and Grain Products Safety

Xiaonan Sui[1], Yan Zhang[2], Zhongjiang Wang[1], Baokun Qi[1], Yang Li[1] and Lianzhou Jiang[1]

[1] *Northeast Agricultural University, Harbin, China*
[2] *National University of Singapore, Singapore*

31.1 Introduction

Grain food is one of the essential needs for human survival as it is a rich source of carbohydrates, vitamins, minerals, and dietary fiber. As such, grain food is very much intertwined with the physical and mental well-being of the public. Threats to grain safety will not only impact public health in China, but will also affect the country's stability and economic development. Despite the large focus on the grain industry, there have been multiple grain scandals and issues related to grain safety in the past decade due to the delayed development of a firm grain safety policy in China. These problems have not only affected public health, but also the credibility and status of Chinese grain products internationally. Consequently, a review of previous, current, and potential grain safety-related problems is necessary to assist in developing policies for sustaining safe grain production, and ensuring grain safety.

31.2 Past Grain Safety Problems in China

Grain products are susceptible to spoilage by insects and microorganisms during storage phases, resulting in an overall decrease in quality. Hence, there is a need to adopt safe and efficient storage practices to ensure the quality of grain products [1]. The annual loss of grain in China in 2005-2010 due to wastage was over 8%, far higher than the average loss rate in developed countries. This was due to a lack of storage facilities and the absence of advanced storage technologies [2]. However, recent developments in green technologies in China have resulted in an increase in the usage of methods such as mechanical ventilation, steam circulation, grain cooling, storage automation, and grain inspection, which effectively combat wastage from pest losses and contamination from fungal toxins [3]. Advancements in grain storage technologies have seen a shift from traditional storage techniques to more modern methods, with an emphasis on natural ecological storage. In 2007, the China State Administration of Grain (CSAG)

Food Safety in China: Science, Technology, Management and Regulation, First Edition.
Edited by Joseph J. Jen and Junshi Chen.

implemented a storage program for grain farmers that oversaw the installation of 677 million new units in the country's 26 provinces in an attempt to modernize the grain storage system. This initiative resulted in a 6.5% drop in overall grain loss. The Academy of the State Administration of Grain (ASAG) was established in 2009 to broaden the country's research into grain storage technologies and other applications. Since 2010, there has been more research conducted in China on modern grain storage, such as the utilization of low temperatures, and oxygen and modified atmospheric storage, in an attempt to modify or improve the grain storage process [4]. During the 2014 Asia-Pacific Economic Corporation (APEC) meeting in Beijing, the APEC Food Safety Roadmap Towards 2020 was revised, allowing for a decrease of 10% in total food loss.

31.2.1 Contamination of Food Products During Grain Processing

Over the past decade, China has been committed to reducing the amount of pesticide residues in grain products. Studies have indicated that the treatment of grain products with high temperatures or alkaline solutions can effectively reduce the amount of pesticide residues in them [5].

Contamination of grain products by heavy metals is largely from the soil. In a study conducted in 2007, approximately 10% of the 91 rice samples randomly sampled from Northeast China had a cadmium content exceeding recommended levels. In a follow-up study conducted in 2008, 63 rice samples were randomly obtained, 60% of which contained cadmium at levels exceeding recommended levels [6]. The national standard for maximum levels of contaminants in foods (GB 2762-2005) was introduced by the Ministry of Health (MOH) and the Ministry of Agriculture (MOA) in 2010. According to the national standard, cadmium intake by humans from foods should not exceed 71.4 μg per day. In January 2013, the General Office of the State Council issued a document entitled "Circular on Recent Arrangement on Soil Environmental Protection and Integrated Remediation/Treatment." The document proposed a reduction in the use of chemical fertilizers and pesticides, as well as a reduction in industrial pollution, in order to combat soil pollution. However, in August 2013, the use of aluminum phosphide as a grain fumigant resulted in six deaths in the city of Zhumadian due to the production of toxic phosphine gas under high humidity, contaminating the grain products [7]. This showed that, despite the new legislation to reduce contamination, it was still challenging to enforce the regulations.

Grain poisoning incidents due to contamination by microorganisms are particularly rampant as well. Thirteen children were exposed to contaminated rice at a kindergarten in the Heilongjiang province and developed clinical symptoms indicative of intoxication, such as diarrhea, nausea, and body rash, after consuming contaminated rice for a period of one month. Results from microbiological and toxicological testing of the contaminated rice showed the presence of high amounts of bacterial toxins, which was responsible for the grain poisoning [8]. In order to reduce the risk of microbiological contamination, grain products should be subjected to adequate processing conditions, such as low temperatures, oxygen, and moisture. Currently, the grain industry mainly uses windmills and cleaning sieves to reduce the risk of contamination during grain processing, as well as visual, odor, and physical inspection to ensure that the physical and sensory properties of grain products do not change during processing [9]. Hence, there is still a need for the grain industry to move away from the past and adopt modern practices in order to reduce grain contamination.

31.2.2 Formation of Toxic By-Products During Grain Processing

Grain products may be contaminated by harmful chemicals such as acrylamide, chloropropanols, and benzopyrenes, which are formed as by-products during the initial processing stages. In 2010, the Hong Kong Consumer Council conducted a survey of 90 different types of crispy snacks, biscuits, and cereals, and found that 89 of such market samples contained acrylamide that exceeded recommended levels. Acrylamide is a known carcinogen for humans [10], and excessive concentrations may be produced during improper processing methods [11]. Acrylamide may also be produced during deep frying of grain products, especially if the temperature or duration of frying is too high. In recent years, there has been much research conducted on the inhibition of acrylamide formation through the use of techniques such as the microwaving of grain products, or through the addition of radical scavengers such as ascorbic acid [12]. In 2009, the MOH published a risk assessment of acrylamide in grain products and recommended preventing the overcooking of grains in order to reduce the formation of acrylamide.

In a study conducted by Velíšek [13], it was suggested that chloropropanols, which are produced during grain processing due to reactions within the grain matrix, may be carcinogenic to humans. Previous studies detected low amounts of chloropropanols in baked bread, but the quantity was not sufficient to cause cancer in humans [14]. In the production of artificial soy sauce, chloropropanols may be produced through the substitution of a hydroxyl group by chlorine under alcoholic conditions during the hydrolysis of soybean fats by hydrochloric acid [15]. Experts from the Food and Agriculture Organization (FAO) also suggest that, at current intake levels, chloropropanols do not have any carcinogenic effects on the human body. But, it would be unwise to rule out chloropropanols as a human carcinogen at present. Currently, the national standard states that the chloropropanol content in soy sauce should not exceed 0.2 mg/kg.

Benzopyrenes are common by-products found in instant noodles and processed oils. There was an increase in the number of benzopyrene-related food poisoning cases between 2005 and 2013. For example, in 2007, a fatty acid supplement of European origin that was marketed in China was found to have benzopyrene levels exceeding regulatory standards. In 2012, three commercial oil products (red tea seed oil, sesame oil, and tea oil) in Hunan were found to contain benzopyrenes at levels far higher than permissible. The levels of benzopyrenes in grain products can be lowered by controlling the temperature and duration when they are processed in oil. While such toxic by-products of grain processing may not present any acute toxicity, they are known to be teratogenic and carcinogenic. Therefore, the presence of these compounds should be strictly controlled in grain processing.

31.2.3 Grain Safety Problems Arising from Misuse of Food Additives

Food additives are often added to grain products during processing to prolong the storage life of the finished products. However, excessive or incorrect use of certain food additives, such as aluminum salts, may result in toxic side effects, which include damage to the human nervous and reproductive systems [16]. For example, between 2005 and 2010, hydrated potassium aluminum sulfate (potassium alum) was added during the processing of fried dough fritters. The use of potassium alum was discontinued after it was shown to have harmful human side effects, and safer alternatives, such as ammonium hydrogen carbonate, were used in its place [17].

Nitrite salts are known to have antimicrobial properties, and are more commonly used in cured meat products. They are also used during grain processing in order to extend the shelf life of processed grain foods. However, they also possess acute toxicity, and ingestion of 0.2 to 0.5 g of such salts can result in poisoning, while death may result from a higher intake of 3.0 g [18]. Several cases of nitrite poisoning took place in China during the period of 2004–2011. In 2004, grain manufacturers mistakenly used a nitrite salt as table salt (sodium chloride), which resulted in the "Poisoned dough fritters" incident in the city of Taizhou. Recently, authorities have cracked down on the use of nitrite salts in the production of grain products. Food and beverage outlets have since been prohibited from purchasing, storing, and using nitrite salts [19].

Sulfur dioxide is commonly used as a bleaching agent and preservative in food processing. Although it does not cause any acute toxicity in small amounts, it is highly toxic at higher concentrations and may cause vomiting, diarrhea, and other serious harmful effects to the body [20]. In 2008, a shipment of Chinese starch was withheld by customs authorities in Yokohama, Japan for exceeding regulatory standards of sulfur dioxide. In 2012, a random sampling of market products in Beijing by a supermarket chain found that four types of food products had excessive amounts of sulfur dioxide, due to the use of sulfite salts as a food preservative and the use of sulfur compounds as fumigants. In light of this, food manufacturers and producers should discontinue the use of sulfite salts and sulfur compounds during food processing.

Presently, the use of food additives in China is regulated by the Measures for the Administration of New Food Additives and by the Food Safety National Standards for the Usage of Food Additives, both of which are directives by the General Administration of Quality Supervision, Inspection, and Quarantine (AQSIQ).

31.3 Current Grain Safety Problems in China

In recent years, there has been a strong drive by the Chinese government to develop grain products free of contaminants and adulterants in an effort to boost citizens' trust in local produce. In March 2014, the local administration of Nantong conducted a city-wide sampling of nine different grain products, including extruded grains and fermented grain products, and subjected them to physicochemical and microbiological tests, with the focus on detecting the presence of chemical adulterants and pesticide residues. Results obtained from this sampling indicated that all the grain samples passed the chemical and microbiological tests, which suggested that China's grain regulations and supervision of domestically produced grain products were within expectations. However, due to a persistent lack of mandatory testing of grain products in other parts of China, there have been several recent grain safety issues.

31.3.1 Grain Safety Challenges Due to Biotoxins

Statistics have shown that 25% of the world's grain products are annually contaminated by mycotoxins [21]. Over 350 different types of mycotoxins have been found, many of which have adverse effects on humans and animals. Mycotoxins that have the most harmful effects on grain products include, but are not limited to, deoxynivalenol, zearalenone, fumonisins, aflatoxins, and trichothecenes [22]. Aside from being a direct cause of death in intoxicated animals, a major concern regarding mycotoxins is their perennial, debilitating effects on the immunity and reproductive health of intoxicated animals. These detrimental health consequences can be passed onto humans through the consumption of infected animals and animal products, including meat, eggs, and dairy products, thereby endangering the health of consumers [23–25]. Food safety information disseminated by the Guangzhou Municipal Food Safety Office showed that a multi-cereal of German origin (Jason six corn mush) was found to contain mycotoxins at more than twice the allowed levels, while Sui Feng Yuan Brand Black Sesame Cream contained close to nine times permitted levels. In an attempt to curb food contamination by biotoxins, a revised set of measurements for deoxynivalenol, zearalenone, and aflatoxin B1 in cereals and grains was implemented by the AQSIQ on 1 June 2014. In April 2015, with infants as the main consideration, Taiwan implemented appropriate testing methods for the detection of aflatoxin B1 in infant cereals.

31.3.2 Grain Safety Challenges Due to Chemical Contaminants

31.3.2.1 Residual Pesticide Contamination

The widespread production and use of pesticides and fertilizers in the cultivation of crops saw the emergence of problems brought about by the consumption of their residues in grain food products. Throughout the world, approximately 1000 different synthetic compounds are used as bactericides, algaecides, insecticides, and defoliants, with the annual production of pesticides reaching close to two million tons [26, 27]. The extensive use of these chemicals has led to severe chemical and ecological pollution, threatening human health [28]. In order to encourage the reduction of chemical pesticide usage, while still increasing grain yield, Bayer Crop Science AG has proposed the "Much More Rice" project in collaboration with the agricultural departments in Jianli county within the Hubei province. The joint program organized numerous demonstrations and training events to educate the farming community on proper pest control and use of chemical pesticides so that grain yield and quality will not deteriorate and might possibly be enhanced, despite a decreased use of chemicals.

Safety and environmental concerns stemming from the use of chemical pesticides have resulted in the restructuring of this industry [29]. Findings published by the Department of Statistics in the first quarter of 2015 indicated a near-zero increase in production of chemical pesticides at 0.02%, a new low in recent years. The recently published National Standard on Maximum Residue Limits for Pesticides in Food (GB 2763-2014) has prevented the misuse and abuse of agricultural pesticides and provided standards for food production, analyses of pesticide residues, and regulatory standards for law enforcement agencies.

31.3.2.2 Heavy Metal Contamination

The massive mechanization of agricultural processes and the resultant increase in waste products has led to greater pollution of the environment. Of all the various pollutants, heavy metals have exhibited the most persistent and damaging effects on human health [30, 31]. In China, metals such as cadmium, nickel, copper, arsenic, mercury, and lead are found to be the major heavy metal contaminants in arable land. The concentration of cadmium exceeds allowable amounts in various areas [32]. Led by the MOA and the Environmental Protection Institute, the "Rice Comprehensive Prevention and Control of

Heavy Metal Pollution in the South" initiative was started in the Hubei Province in March 2015 to address problems brought about by heavy metals contamination by implementing measures on a technical level to prevent, treat, and control heavy metals in crops.

31.3.3 Grain Safety Challenges Due to the Misuse of Grain Additives

Grain additives are food ingredients that are added during processing to improve the sensory and physicochemical properties of food products, and can be said to heavily influence the modern grain industry. However, there has been an increase in the misuse of grain additives. An example is aluminum salts, which are used as leavening agents in the production of steamed breads, cakes, and other baked products. Excessive use of aluminum salts can cause serious harm to the human nervous system, especially during early childhood development. A recent study estimated that one in three individuals in China consume excessive amounts of aluminum salts in their diets, with the greatest prevalence found amongst children between the ages of four to six. In light of this, the National Health and Family Planning Commission revised the use of food additives containing aluminum, banning the use of these additives in extruded grain products.

In a recent random sampling of commercial dumpling flour products conducted by the China Food and Drug Administration (CFDA), more than 1761.32 kg worth of commercial products were found to contain food additives exceeding national standards. This incident increased public awareness of the lack of regulation and supervision from government authorities concerning food additives, resulting in calls to strengthen supervision and enforcement of food regulations. The updated Food Safety National Standards for the Usage of Food Additives was revised last year (GB 2760-2014) and has been lauded as having the potential to improve safety and use of food additives.

31.3.4 Grain Safety Challenges Due to Overprocessing of Food

The proportion of grain produce in China that is suitable for human consumption amounts to approximately 65–70% of the total grain produced [33]. That is to say, for every ton of wheat produced and processed, a total of 0.6 tons of wheat flour is obtained, and the remaining 0.4 tons of wheat endosperm is discarded for use as animal feed. Overprocessing of grain not only results in a loss of nutrients, but also in a loss of other resources, such as energy spent on food processing and other natural resources. Furthermore, it results in an increased risk of hazards, such as increased levels of acrylamide and other substances in the finished product [34]. In a 25-year study published in the Journal of the American Medical Association (JAMA) Internal Medicine, consumption of whole grain food products has been associated with a lower rate of cardiovascular diseases. According to the Food and Nutrition Development Guideline (2011–2020) released by the State Food and Nutrition Consultant Committee, the food industry in China should be placing emphasis on developing wholegrain food products and the relevant authorities should promote research and encourage public consumption of wholegrain products and healthier food alternatives.

31.3.5 Genetically Modified (GM) Grain Safety Challenges

To combat the risk of crop failure due to crop diseases, research institutes in China have commenced studies on genetically modified (GM) soybean and rice that are resistant to fungal infections. Production of GM crops not only results in an overall yield increase, but also contributes to environmental safety and sustainable development. However, there is still controversy regarding the use of GM crops. Professor Chen Junshi from the Chinese Academy of Engineering has mentioned that the main reason for the lack of acceptance of GM food is due to the lack of understanding of the technology. The safety evaluation of GM foods is based on scientific understanding and consumption of GM foods has not been found to cause any acute or chronic disorders. The use of GM crops has been predicted to play a significant role in addressing issues of food and environmental sustainability in China, and can be seen by the production of 3.9 million hectares of GM crops in 2014.

A newly released report entitled "Genetically Engineered Crops" from the US National Academy of Sciences addresses their findings regarding the safety problems of GM crops [35]. After reviewing more than 700 comments, documents, and relevant literature, the National Academy of Sciences committee concluded that the available time-series epidemiological data do not show any disease or chronic conditions in populations that correlate with the consumption of GM foods. Furthermore, the committee mentioned they could not find persuasive evidence of adverse health effects directly attributable to consumption of GM foods.

31.3.5.1 Overview of GM Rice

In the next 5 to 10 years, global rice production is predicted to remain constant, while the world population is predicted to grow to 8 billion by 2020. To meet the dietary needs of the growing world population, rice production will need to be increased by 25–40% over the next five years [36]. GM rice has received international attention for its excellent characteristics, such as pest- and disease-resistance, and higher content of key vitamins and minerals. The United States, Japan, China, and several other countries have achieved major breakthroughs in GM rice research, and have successfully cultivated a number of GM rice varieties and conducted relevant laboratory and field experiments on them. However, GM rice cultivation has yet to be introduced on farms on a large scale, due to biosafety, public health, and economic concerns, which urgently require further discussion.

Development of GM rice is mainly performed through direct DNA transfer or agrobacterium-mediated transformation technologies [37]. During the initial stages of the development of GM technology, Ayres, Tyagi, and other researchers [38–40] focused on successfully establishing high-frequency transformation protocols and optimized gene delivery methods. Subsequently, more emphasis was placed on improving crop production by accelerating the growth of the GM crop. At this time, rice was frequently used as a model monocotyledonous system [41]. Recently, increasing emphasis has been placed on improving agronomic and nutritional traits, making crops more resistant to insects and superior in nutritional quality [42]. Yet, due to safety concerns and negative public perception, commercial cultivation of GM rice is still not practiced on a large scale in any country.

31.3.5.2 Chinese Government's Attitude Toward GM Rice

Due to the many benefits that GM rice could possibly bring, it is inevitable that many developed countries will eventually adopt the associated GM biotechnology. In this vein, China's central government issued the first policy document that addressed the management of food safety research and the promotion of research on agricultural genetically modified organisms (GMOs) in 2015. This signaled the central government's recognition of GM biotechnology as a vital part of expanding the agricultural industry in the future. Despite the implementation of this recent official policy, there has been some notable research and development of GM rice that has been conducted in China for several decades. In particular, researchers from Huazhong Agricultural University developed cry1Ab/cry1Ac GM insect-resistant rice in 1999. In 2003, the MOA approved 2000 acres of farmland for cry1Ab/cry1Ac GM rice production tests. After 11 years of research, demonstrations, and quality assessments, two kinds of GM insect-resistant rice were awarded safety certificates in early 2009, which expired on August 17, 2014. However, they have not yet obtained approval for commercialization. As yet, there are no GM rice products available in the market in China. Quoting Yuan *et al.*: "We just did a test in Shenzhen farm, but the market has not." However, the reluctance to approve commercialization is very likely due to the intense controversy and the negative perception surrounding GM crops.

31.3.5.3 Safety Assessment of GM Rice

The most important safety assessment of GM foods is their influence on the environment [43]. Without such studies, GM rice cannot be used as food for human consumption, or as animal feed, even though agronomical and nutritional traits have been successfully incorporated into them. The various safety assessments of GM rice include substantial equivalence of nutrition, nutritional assessment on animals, *in vivo* and *in vitro* toxicology studies, allergenicity assessment, and horizontal transformation of introduced gene studies [44].

Nutritional equivalent analysis is achieved through comparative analysis of GM rice and conventional rice varieties [45]. This analysis can reveal significant unforeseen effects [46]. To date, Zou has found that GM rice with *cry2A** gene is resistant to *Lepidopteran* insects, and poses no adverse effects on human and animal health [47]. Dipak has found no significant differences between transgenic *Xa21* rice and conventional rice in terms of nutritional composition. Furthermore, they did not detect new toxins or allergens in the transgenic rice [48]. Momma [49] performed feeding studies on rice genetically modified with soybean glycerin for four weeks, using rats. The result was that the transgenic rice had the same nutritional and biochemical characteristics as the GM-free rice. Italian researchers studied the safety of GM Bt176 corn, and after feeding sheep and their offspring for three years, they found no adverse effects on their health [50]. German researchers evaluated the safety of rice that could express bean agglutinin E by subjecting rats to a 90-day feeding experiment [51]. In recent years, Chinese research on GMOs has reached a breakthrough. Dr Zhang Qifa's team from Huazhong Agricultural University has made significant contributions in the genetically modified rice area through developing a series of related products, including Bt rice and vitamin A-rich golden rice [52, 53].

In addition to the comparison of nutrition, animal feeding tests were also conducted to assess the food safety of GM rice. Although some differences between transgenic lines and wild type were observed in the feeding tests, most researchers assumed that the differences were within the natural range and the nutrition and safety level of the GM rice were regarded to be similar to their parental non-transgenic counterparts.

However, there was still some evidence showing negative effects of GM rice. Several findings proved the alteration of intestinal flora and some biochemical indicators in the test animals. Especially, the toxic effect of the Bt rice has been documented, which should be further verified. Few feeding tests over 90 days have been carried out. Therefore, longer-term feeding experiments are suggested. This conclusion will be helpful for food safety assessment of GM rice, and may also provide evidence for biosafety management [54]. Dr Zhang further tested their developed GM rice and suggested that the it tasted good, had no obvious changes in shape and texture after the second heating, and met the national standard for high-quality rice [55]. However, consumers are still worried about safety problems with regard to consuming GM rice. Transgenic technology involves all aspects of society and the Japanese government has publicly announced that views expressed by their citizens need to be listened to before transgenic crops are officially recognized. People are encouraged to vote and express their recommendations when the genetically modified food is identified. However, Dr Zhang suggested that the industrialization of GM rice should not only rely on public opinion, but go in accordance with regulations and procedures [53].

Nowadays, according to the safety situation of transgenic products, China will allocate more resources to enhance the development environment for GM agriculture, and encourage scientific research and innovation in the agricultural sector. Hence, it is an urgent task to continue to comprehensively and objectively evaluate the safety of GM rice and other GM grains by conducting more scientific experiments.

31.4 Potential Future Grain Safety Problems in China

31.4.1 Increasing Demand for Grain

The growth in the demand for food in China today is largely driven by two aspects: population growth and an increase in the overall standard of living. It is predicted that China's population is likely to peak at 1.45 billion by 2030. In order to provide a stable food supply of 400 kg per capita, the amount of grain required will be a staggering 0.58 trillion kg – 85 billion kg more than the current demand of 495 billion kg [56]. In addition, the increase in the standard of living will result in increased demand for foods that are rich in high-quality protein, including meat, poultry, and eggs. For every kilogram of meat produced, 1.5 to 3.5 kg of grain is consumed [57, 58]. An increase in demand for high-quality protein will indirectly lead to an increase in demand for grain for animal feed.

China's current grain production capabilities are able to meet the needs of its citizens. However, due to factors such as climate change, price fluctuations, and policy adjustments, the yearly food production and harvest face issues of periodic and structural imbalances and fluctuations. This is closely related to potential hazards such as the reduction in arable land, the destruction of the ecological environment, the shortage in water resources, and the weakening of agricultural foundations [59]. For example, the great agricultural state of Hunan, also dubbed the "land of fish and rice," suffered a severe drought in 2013, causing a decrease of 2.7% in grain yield. Agriculture, animal husbandry, and aquaculture in some parts were also severely affected, resulting in a decrease in grain and the bulk of agricultural produce for the first time.

31.4.2 Grain Safety and Technology

Grain safety and technology are closely related, and in many aspects, the advent of new technologies has improved the safety, quality, and availability of grain production [60, 61]. For the consumers, technology has allowed for better nutritional quality through nutrient fortification and improving the amino acid balance. New GM techniques, such as the use of lodging-resistant genes to improve crop yield and quality, have helped increase farmers' income. With higher crop yields and more nutritious food available, more people in China will be food secure.

31.4.3 New Technologies for Grain Storage

With the continuous advancement in grain storage technologies, the country's concept of grain storage is also evolving gradually toward "green, ecological, intelligent, and efficient" eco-storage. Currently, the "four-in-one" grain storage technologies – machine aeration, recirculation fumigation, grain cooling, and grain inspection – are effectively being used for pest control and the prevention of growth of mold and mildew [62]. It is estimated that the use of these technologies has resulted in a 3% reduction in the loss of reserves, an increase in the deposit rate from 70% to 99%, and an 80% reduction in the consumption of grain storage chemicals. In the future, more technologies, such as heat insulation, recirculation fumigation under film, and slow-release ventilation may be encouraged to safeguard the food safety of China.

31.4.4 Implementation of Public Policies to Safeguard Grain Safety

With the rapid globalization of the economy, grain safety issues are becoming more recognized internationally. Based on the measures that certain countries in the world take toward grain safety, one accepted international practice is the policy of grain price protection. Its basic objective is to ensure the relative balance between grain supply and demand, and thus the stability of grain prices, targeting grain safety via cost control. This also prevents enterprises from utilizing harmful raw materials in order to reduce costs [63]. However, safeguards and measures for grain safety, including production, consumption, reserves, and trade, could be established as a first line of defense for China's grain safety, an early warning mechanism, with the purpose of identifying trends and signals in the food supply. This would allow policy-makers to make the necessary adjustments to the food reserves in order to ensure stability in food supplies despite varying yearly harvests [64].

A second line of defense for China's grain safety is the establishment of a sound law enforcement agency, conducting active grain law enforcement on the ground and constructing quality inspection centers. These will holistically strengthen the supervision of grain processing safety, and place stricter controls on chemicals and additives banned by the state [65]. For instance, some European countries have already banned the use of methyl bromide as a fumigation agent, but some of China's private enterprises still use it.

As a third line of defense, China can participate in internationally recognized standards in order to align China's grain product standards with global standards. For example, it could establish a comprehensive ISO9000 quality system and encourage the implementation of GMP and HACCP quality assurance systems and other similarly effective methods. In 2014, the Global Food Safety Initiative (GFSI), which brings together CEOs and senior management from over 650 retailers, manufacturers, service providers, and other stakeholders across 70 countries, proposed the establishment of an international standards and certification program, which includes a food safety risk communication mechanism and recognition program [66, 67]. The GFSI is another avenue that China could take part in to strengthen its food standards regulation program.

31.4.5 The Promotion of New Advanced Technologies to Ensure Grain Safety

The application of new and advanced technologies will bring new vitality to the development of grain safety and inspection technologies [68]. In 2014, with the help of new technologies, China has achieved a series of breakthroughs in cultivating more than 1500 new varieties and combinations of high-quality, high-efficiency, and multiply resistant crops. This has resulted in a two- to threefold increase in varieties of major oil and grain crops.

Innovation has achieved breakthroughs and eliminated several existing problems in the field of rapid detection technologies for food safety in cereals, oils, and foodstuffs, and pollution prevention and control. In recent years, with the accelerated development of new materials, sensing technologies, data acquisition and digital processing, and new intelligent recognition devices have emerged [69]. Devices such as electronic eyes, electronic noses, electronic tongues, and other computer-vision technologies have studied and determined the chalkiness of rice, grain type, percentage of yellow rice kernels, head rice yield, protein content, amylose content, and other related quality indicators [70]. In the future, it is expected that smaller and more intelligent sensing technologies will bring further improvements to the sensitivity of detectors, thus providing better support for grain safety.

31.5 Conclusion

Due to new socioeconomic developments, the standard of living and grain production have gradually improved in China, leading to greater demand for grain foods. China's grain safety is not only an issue of quantity and safety, but also of grain quality, ecological safety, and public health safety. Developed countries place a greater emphasis on grain nutrition and price stability in terms of grain safety. Other than relying on foreign imports of grain products and increasing productivity, Chinese authorities have been limiting pollution to the environment to ensure grain sufficiency, which also provides consumers with a greater variety of healthier grain options.

In light of resource constraints, environmental pollution, and losses to the ecosystem, China has to speed up the advancement of modern agricultural techniques, embrace the use of green agriculture, and develop resource-saving and environmentally friendly processing methods. At the same time, authorities should make use of indicators of public acceptance and examine grain production, processing, storage, and transportation from a scientific point of view to strengthen grain safety. With constant changes in the global, economic, and political arenas, as well as domestic socioeconomic developments, China's grain safety issues should be examined from a wider perspective. Compared to the 1990s, China's present relationships and trade with other countries have improved dramatically. Through active trading with other economies, China can effectively make use of domestic and foreign markets to protect its grain safety. However, China still needs to improve its grain safety while on its way to becoming a developed country.

References

1 Guo, D. L., Yan, X. P. Situation of our grain storage and future trends. *Grain and Oil Storage Science and Technology*, 2008, (4): 2–5 [in Chinese].

2 Yang, G. J., Ren, Y. H., Hu, D. S. Status quo and development trend of grain storage. *Grain Processing*, 2012, 37(1): 60–63 [in Chinese].

3 Wu, C. R., Tang, H. J., Wang, Y. Y. Current Situation and Prospect of grain storage standard system. *Journal of the Chinese Cereals and Oils Association*, 2010, 25(11): 124–128 [in Chinese].

4 Zhang, M., Deng, H., Li, G., Fan, J., Ren, J. Simulation study on impacts of climate change on the production of winter wheat in north China. *Chinese Journal of Agricultural Resources and Regional Planning*, 2011, 32(4): 45–49 [in Chinese].

5 Xu, Z., Lei, H., Wang, H., Yang, J., Shen, Y., Sun, Y. Transformation and safety of exogenous chemical compounds during food processing. *Journal of Food Safety and Quality*, 2012, 5(3): 360–366 [in Chinese].

6 Qi, L., Fu, Z., Shi, Y. Technology of pesticide application and food safety. *Transactions of the Chinese Society of Agricultural Engineering*, 2002, 18(6): 203–206 [in Chinese].

7 Zeng, X. Y., Xie, C. M., Xie, Y. X. Investigation rice cadmium pollution in a city. *Preventive Medicine Tribune*, 2014, 20(9): 653–655 [in Chinese].

8 Zhang, Z. M., Lan, B., Liu, J. R. Application of digital technology in food concentration of phosphine fumigation remote monitoring. *Grain Storage*, 2015, 44(2): 27–29 [in Chinese].

9 Gong, H. N. Relationship of food microbiology and grain storage. *Private Technology*, 2015, (2): 2–3 [in Chinese].

10 Hervey, T. Foundations of EU food law and policy ten years of the European food safety authority. *Common Market Law Review*, 2015, 52(1): 302–303.

11 Jo, Y., Jin, C. Advances in acrylamide analysis and its control in food. *Farm Products Processing*, 2013, (11): 58–64.

12 Zhang, W., Guo, Y., Hao, Y., Li, S. Determination of acrylamide in Chinese oil-fried foods and introductory research on reduction of acrylamide. *Cereals and Oils*, 2011, (12): 23–26 [in Chinese].

13 Velíšek, J., Davidek, J., Hajšlová, J., Kubelka, V., Janíček, G., Mánková, B. Chlorohydrins in protein hydrolysates. *Zeitschrift fur Lebensmittel-Untersuchung und -Forschung*, 1978, 167(4): 241–244.

14 Breitling-Utzmann, C. M., Köbler, H., Herbolzheimer, D., Maier, A. 3-MCPD: Occurrence in bread crust and various food groups as well as formation in toast. *Deutsche Lebensmittel-Rundschau*, 2003, 99(7), 280–285.

15 Wang, W., Hu, Z., Qi, Y., Zhang, W. Research progress of the formation mechanism and reduction of chloropropanol in edible oil. *Journal of Food Safety and Quality*, 2013, 4(6): 1778–1784 [in Chinese].

16 Soni, M. S., White, S. M., Flamm, W. G., Burdock, G. A. Safety evaluation of dietary aluminum. *Regulatory Toxicology and Pharmacology: RTP*, 2001, 33(1): 66–79.

17 Li, L., Wang, L., Qiang, H., Zhang, H., Qi, X. Study on deep-fried bread stick. *Science and Technology of the Food Industry*, 2014, 35(23): 366–371 [in Chinese].

18 Meng, Y. Food Additives - nitrite. *China Food*, 2012, (7): 46–47 [in Chinese].

19 Zhou, B., Xiao, J., Liu, S., Li, Y. Research on nitrite harmful analysis and its substitute in curing meat products. *China Food Additives*, 2012, (2): 166–171 [in Chinese].

20 Liu, Z. J. Study common determination of sulfur dioxide. *Technology and Enterprise*, 2014, (4): 275–276 [in Chinese].

21 Zhang, J. Z., Zhang, A. P., Zhang, H. Feed mycotoxins animal health is becoming invisible killer. *Pigs Today*, 2007, (2): 19–22 [in Chinese].

22 Wang, X., He, C., Liu, H., Zhang, H. Contamination, hazard and detection technology of mycotoxins. *China Animal Husbandry and Veterinary Medicine*, 2009, 41(8): 104–107 [in Chinese].

23 Ge, N., Yuan, H. The development of research on immunosuppression of mycotoxin. *China Animal Husbandry and Veterinary Medicine*, 2008, 35(3): 126–128 [in Chinese].

24 Ma, T. C., Tian, J. J., Ma, Q. T. Mycotoxins on pig hazards and preventive measures. *Technical Advisor for Animal Husbandry*, 2007, (10): 68–69 [in Chinese].

25 Meng, Y. L., Bai, X. Y. Advances in poultry gut health and nutrition control technology. *China Feed*, 2012, (7): 30–33 [in Chinese].

26 Wu, P., Qin, Z., Zhou, X., Wu, T., Xin, M. Research progress of pesticide residues in vegetables. *Journal of Northeast Agricultural University*, 2011, 42(1): 138–144 [in Chinese].

27 Song, W., Shan, W., Ye, J., Li, Z., Zhou, Z., Pan, C. Present situation and development trend of MRLs for pesticides in and outside China. *Chinese Journal of Pesticide Science*, 2009, 11(4): 414–420 [in Chinese].

28 Bu, Y., Kong, Y., Zhi, Y., Wang, J., Shan, Z. Pollution of chemical pesticides on environment and suggestion for prevention and control countermeasures. *Journal of Agricultural Science and Technology*, 2014, 16(2): 19–25 [in Chinese].

29 Zhang, X., Ye, F. Pesticides and environment safety. *Journal of Northeast Agricultural University*, 2007, 38(5): 716–721 [in Chinese].

30 Guo, Y., Song, L. Heavy metal pollution and advances in treatment technology. *Guangzhou Chemical Industry*, 2010, 38(4): 18–20 [in Chinese].

31 Wang, F., Zhou, X. Population factors affecting environmental pollution in China - empirical analysis based on provincial panel data. *South China Population*, 2013, 28(6): 8–18 [in Chinese].

32 Lu, Y., Ruoshiwanga, S. S. Impacts of soil and water pollution on food safety and health risks in China. *Environment International*, 2015, 5(15): 5–16.

33 Ma, T. Status and technology innovation and development of grain processing industry. *Modern Agriculture*, 2010, (10): 20–21 [in Chinese].

34 Zhao, X. Development and application of brown rice whole grain foods. *Grain Processing*, 2014, 39(6): 25–27 [in Chinese].

35 Committee on Genetically Engineered Crops: Past Experience and Future Prospects; Board on Agriculture and Natural Resources; Division on Earth and Life Studies; National Academies of Sciences, Engineering, and Medicine, *Genetically Engineered Crops: Experiences and Prospects*, 2016 [in Chinese].

36 Datta, S. K. Rice biotechnology: A need for developing countries. *Agbioforum*, 2004, 7(1).

37 Bajaj, S., Mohanty, A. Recent advances in rice biotechnology: –Ttowards genetically superior transgenic rice. *Plant Biotechnology Journal*, 2005, 3(3):275–307.

38 Christou, P. Transformation technology. *Trends in Plant Science*, 1996, 1(12):423–431.

39 Tyagi, A. K., Mohanty, A., Bajaj, S., *et al.* Genetically modified rice: A valuable monocot system for crop improvement and gene research. *Critical Review Biotechnology*, 1999, 19, 41–79.

40 Giri, C., Laxmi, G. V. Production of genetically modified rice with agronomically useful genes, an assessment. *Biotechnology Advances* 2000, 18, 653–683.

41 Gowda, M., Venu, R. C., Roopalakshmi, K., *et al.* Advances in rice breeding, genetics and genomics. *Molecular Breeding*, 2003, 11, 337–352.

42 Moghissi, A., Pei, S. Q., Liu, Y. Z., *et al.* Golden rice: scientific, regulatory and public information processes of a genetically modified organism. *Critical Reviews in Biotechnology*, 2016, 36(3):535–541.

43 Oh, S. W., Park, S. Y., Lee, S. M., *et al.* Multivariate analysis for the safety assessment of genetically modified rices in the anti-nutrients and phenolic compounds. *International Journal of Food Science and Technology*, 2015, 51(3): 765–776.

44 Qi, X., Chen, S., Yao, S., *et al.* Safety assessment of genetically modified rice expressing human serum albumin from urine metabonomics and fecal bacterial profile. *Food and Chemical Toxicology*, 2015, 76: 1–10.

45 Oh, S., Park, S. Y., Yeo, Y. S., *et al.* Comparative analysis of genetically modified brown rice with conventional rice varieties for the safety assessment. *International Journal of Food Science and Technology* 2015, 50: 1244–1254.

46 García-Cañas, V., Simó, C., León, C., *et al.* MS-based analytical methodologies to characterize genetically modified crops. *Mass Spectrometry Reviews*, 2011, 30(3):396–416.

47 Zou, S., Huang, K., Xu, W., *et al.* Safety assessment of lepidopteran insect-protected transgenic rice with cry2A* gene. *Transgenic Research*, 2015: 1–10 [in Chinese].

48 Dipak, G., Soumitra, P., Sailendra, N. S. *et al.* Comparative nutritional compositions and proteomics analysis of transgenic Xa21 rice seeds compared to conventional rice. *Food Chemistry*, 2016, 203(15): 301–307.

49 Momma, K., Hashimoto, W., Yoon, H. J., *et al.* Safety assessment of rice genetically modified with soybean glycinin by feeding studies on rats. *Bioscience Biotechnology and Biochemistry*, 2000, 64(9): 1881–1886.

50 Trabalza-Marinucci, M., Brandi, G., Rondini, C., *et al.* A three-year longitudinal study on the effects of a diet containing genetically modified Bt176 maize on the health status and performance of sheep. *Livestock Science*, 2007, 3(9): 1–13.

51 Morten, P., Malene, S., Andrea, W., *et al.* Safety testing of GM-rice expressing PHA-E lectin using a new animal test design. *Food Chemical Toxicology*, 2007, (45): 364–377.

52 Zhang, Q. F. Developing genetically modified crops. *Journal of Huazhong Agricultural University (Social Science Edition)*, 2010, 01: 1–6 [in Chinese].

53 Hao, C., Lin, Y. Review and prospect of transgenic rice research. *Chinese Science Bulletin*, 2009, 54(22): 4049–4068 [in Chinese].

54 Jiao, Z., Guo, Y., Kong, H., *et al.* Progress on environmental safety evaluation of transgenic rice. *Chinese Journal of Tropical Crops*, 2013, 34(12): 2521–2526 [in Chinese].

55 Yang, W., Guo, Z., Huang, C., *et al.* Combining high-throughput phenotyping and genome-wide association studies to reveal natural genetic variation in rice. *Trolleybus Magazine*, 2014, 5(6): 92–96 [in Chinese].

56 Zhong, Z., Kong, X., Zhong, W. Food safety: Century challenges and responses. *China Grain Economy*, 2011, (8): 15–17 [in Chinese].

57 Wu, L. China's grain economy entering a new stage: Characteristics, reasons and solutions. *Agricultural Economics and Management*, 2014, (1): 28–34 [in Chinese].

58 Wu, Z. D., Yang, W. S. Our food Safety situation and prospects oils and technology. *Science and Technology of Cereals, Oils, and Foods*, 2008, 16(5): 1–4 [in Chinese].

59 Wang, Y., Xu, G. Food safety of china in the process of economic globalisation. *Journal of Jilin Agricultural University*, 2014, 36(2): 243–249 [in Chinese].

60 Li, W. China's food Safety situation and countermeasures current. *China Grain Economy*, 2012, (9): 20–24 [in Chinese].

61 Li, L. T., Xue, J. L. World food Safety trends and predictions. *Journal of Shanghai University (Social Science Edition)*, 2009, 16(3): 29–36 [in Chinese].

62 Li, G. X. China's grain production capacity and national level to ensure food Safety analysis 2020. *Chinese Rural Economy*, 2014, (5): 4–12 [in Chinese].

63 Huang, H. Q. Development of food processing industry to ensure national food Safety. *China National Conditions and Strengths*, 2013, (3): 16–18 [in Chinese].

64 Zhu, J., Li, T. X., Li, D. Y. Thinking "by Nine" after: The contribution of grain internal restructuring and the future potential analysis. *Issues in Agricultural Economy*, 2013, (11): 36–45 [in Chinese].

65 Yang, W. J. *Economic Development of Rice Industry*. 2013 [in Chinese].

66 Mao, M. J. Central rural work conference bifocal food safety and agricultural modernization. *Shanghai Securities News*, 2013-12-24 [in Chinese].

67 Zou, C. X. Central economic work conference focus: Food safety as the first task of the six. *Beijing Youth Daily*, 2013, 12(14): 1-–2 [in Chinese].

68 You, X. Corn processing of circular economy development. *Grain Processing*, 2007, 32(1): 14–18 [in Chinese].

69 Wang, R. Y. Basic situation of China's grain and oil industry and the development trend in the future. *Cereal and Food Industry*, 2007, 14(4): 1–4 [in Chinese].

70 Hu, G., Wang, J., Wang, X., Dong, X., Zhu, J. Study progress and prospects for technology of detection for quality evaluation in cereal and oil. *Journal of the Chinese Cereals and Oils Association*, 2011, 26(3): 110–118 [in Chinese].

32

Food Safety Aspects of Aquatic Products in China

Felicia Kow[1] *and Junrong Liu*[2]

[1] *University of Tasmania, Tasmania, Australia*
[2] *Dalian Ocean University, Dalian, China*

32.1 Chinese Aquatic Products: Supply and Consumption

In the process of cultivating plants and domesticating animals, our human ancestors shifted from food gatherers to food producers. Today, agriculture provides the majority of human food crops and livestock, which comprise cultivated and domesticated species. The marine environment, however, still provides mankind with a considerable amount of wild food. If we say that the agricultural revolution has increased the production of raw materials, then food science and technology enable their effective use. The result has increased food security and human well-being, and thereby earth's population has increased. Until relatively recently, the oceans have provided copious amounts of seafood and high-quality protein, but dwindling marine resources over recent years have led to an increase in farmed, economically important aquatic species. Successfully bred species include salmon, tilapia, catfish, prawns, and so on.

After 30 years of economic development in China, current consumer demand for fish is the inevitable result of the pursuit for a better quality of life. No doubt, the development of aquaculture has contributed much to its ever increasing demand by the Chinese population, which is the largest in the world.

32.1.1 The Development of Chinese Fishery Production

Current seafood consumption patterns in China are derived from changes to traditional fisheries in the late 1970s and their progressive development thereafter. Over the past 60 years, China has experienced three stages, namely, "fish scarcity", "fish sufficiency" and "fishery industry development". Today, an important issue facing China is sustainable fisheries development.

Between 1950 and 1980 China's agricultural structure was divided into five subcategories: agriculture, forestry, animal husbandry, livestock and fisheries [1]. The fisheries industry was initially very small scale, with its status compared to large-scale farming dubbed as "Fifth and dispensable" [2, 3]. The economic marketing model at that time was based on collective local production and supply, unlike today's national

Food Safety in China: Science, Technology, Management and Regulation, First Edition.
Edited by Joseph J. Jen and Junshi Chen.

and international markets [4]. Therefore, before the 1980s, consumers often encountered "fish scarcity".

In 1978 the country started reforming and opening up the fishing industry, so "fish scarcity" became a concern for the government [5]. The first step in solving the problem of fish supply was to reform the marketing system [6] and fisheries taking the lead in market-oriented reform provided a full and free supply until 1985 [4]. The second step was to adjust the structure of the fishing industry [7]. The basis of commercial fisheries became aquaculture, which provided increased quantities and varieties of breeding species. This, coupled with the continual upgrading of breeding technology [8] meant China's aquatic production structure underwent fundamental change. The annual average aquaculture production increased by 14.8% [9]. In 1985 the total annual production increased to 1 million tons and by 1988, China's production broke through the 10 million tons barrier. Aquaculture production surpassed the wild catch [10]. At the same time, when China opened offshore fishing in the mid-1980s [11], coastal fishery resources gradually decreased.

Figure 32.1 shows Chinese aquatic food production over the decade since 2005 from marine fishing, mariculture, freshwater aquaculture, freshwater fishing and distant deep-sea fishing [12].

32.1.2 Chinese Seafood Consumption Characteristics

China's daily per capita intake of fish protein ("fish refers to economic aquatic species), 6–10 g, is 20% more than the total animal protein intake [13]. The characteristics of Chinese fish consumption can be summarized as: (i) consumption species diversity, (ii) diversity of traditional consumption habits and (iii) variability of emerging consumption patterns. Figure 32.2 shows a basic overview of China's current aquatic industry chain.

Taking fish as an example, inland consumers have traditionally favored freshwater fish, whilst sea fish are preferred on the southeast coast. Along with urban population

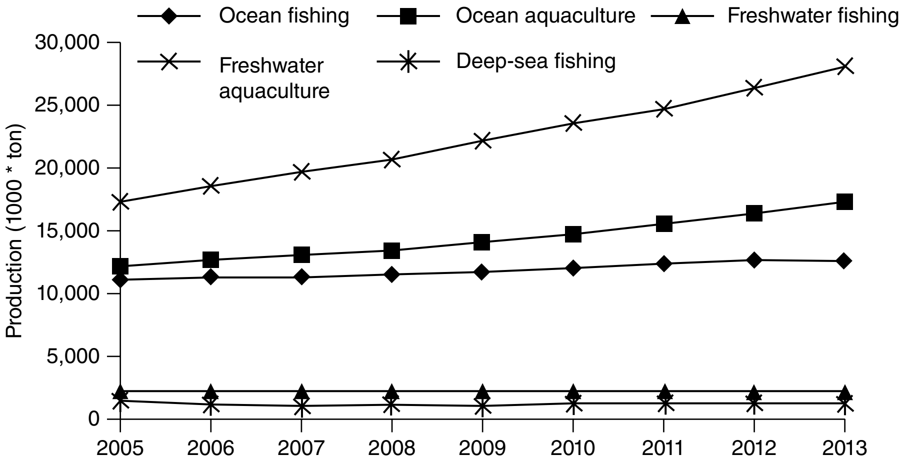


Figure 32.1 Chinese aquatic production layout and trends (2005–2013) *Source:* China Fishery Statistics Yearbook (2006–2014).

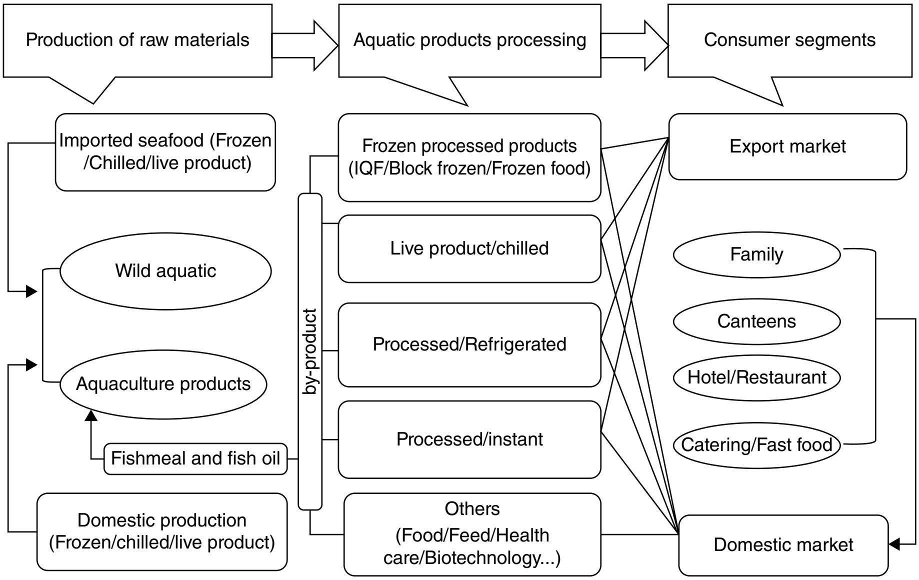


Figure 32.2 A profile of China's aquatic products industry chain (Source: Liu, 2014 [108]).

growth, lifestyle changes have promoted the development of the catering industry, which has led to consumers in many coastal cities favoring specialty dishes of freshwater fish, influencing traditional consumption patterns. For example, Sichuan cuisine flourished greatly, contributing to the popularity of the country's consumption of freshwater fish; whilst the consumption of Japanese and Western dishes, as well as other exotic fish imports, was fueled mainly by those in the higher socio-economic demographic. Unfamiliar species from other parts of China and abroad continued to flood the market. Meanwhile, the inexperience of fish marketing management sometimes led to misleading labelling, resulting in consumer disputes and even food poisoning, such as the "fake-cod" diarrhea incident, which caused numerous consumer complaints [14, 15]. At present, Chinese consumers are still faced with varieties of unfamiliar aquatic products, controversial safety incidents or exaggerated reporting. Hence, skeptical consumers avoid eating seafood products and do not benefit from the high nutritional value of quality fish proteins, n-3 fatty acids and unsaturated fatty acids.

When it comes to food safety issues, the public need to be informed of basic common facts to avoid irrational panic. In particular, a rational distinction should be made between the concepts of "hazard" and "risk". The difference being that "hazard" refers to agents in food (risk factors) with the potential to cause an adverse health effect, whilst "risk" relates to the likelihood and severity of an adverse effect from exposure to a hazard. The adverse effect can be immediate or longer-term. Adverse effects can also vary in severity from negligible to very high. Hazards are ubiquitous and cannot be eliminated, so there is no "zero risk" food safety system. Minimizing risk to an acceptable level is the principle of food safety management control.

Today, the Chinese consumer's awareness of seafood is provided mainly by a wide range of media outlets, which are run by people, who themselves may be consumers. Scientific and public dialogue have not yet attracted sufficient attention to engender basic common sense and knowledge of aquatic products. This is not conducive to the well-being of consumers' health and is also damaging related industries, which may well ultimately lose their livelihoods.

32.2 Development of Chinese Aquatic Product Quality

An inter-relationship exists between the perishable nature of aquatic products and maintenance of commodity values, which are reliant on freshness. Apart from the natural toxins and environmental pollutants, potential food safety risks exist in the processes of maintaining quality and freshness. One is the endogenous risk associated with the deterioration process, which leads to the accumulation of hazardous substances, such as histamine. The second is the exogenous risk, namely, the illegal intentional or unintentional use and abuse of additives for preservation purposes.

Aquatic food-borne illness can be divided into two types, infection and poisoning. Infectious disease refers to the consumption of toxins from pathogenic microorganisms or seafood contaminated with bacteria, whilst poisoning is caused by eating seafood containing toxic compounds, such as various marine biotoxins, chemical contaminants and bacterial exotoxin (Table 32.1) [16].

32.2.1 Incidence of Aquatic Food-Borne Illness

32.2.1.1 Food Poisoning

Histamine poisoning. Cara marine migratory fish, typically mackerel *(Pneumatopphorus grex)*, tuna, sardines, Pacific saury, mackerel (*Pneumatophorus japonicus)*, horse mackerel and so on, are rich in histidine, which is converted to histamine after death by the enzyme histidine decarboxylase provided by microorganisms. Histamine ingestion leads to human histamine allergies. Inadequate handling practices after capture are the normal causes of histamine food poisoning. There have been such incidents periodically [17], but these have not caused deaths. Although reported mass outbreaks are few,

Table 32.1 Aquatic food-borne disease and hazards.

Type of disease		Risk factors
Infection	Bacterial	*Listeria*, *Salmonella*, *E. coli*, *Vibrio*, *Shigella* bacteria etc.
	Virus	Hepatitis A virus, norovirus etc.
	Parasites	Nematodes, tapeworms and flukes etc.
	Bacterial endotoxin	*Vibrio cholera* toxin, *Vibrio parahaemolyticus* toxin, *E. coli* toxin, *Salmonella* toxin
Poisoning	Bacterial exotoxin	*Staphylococcus aureus* toxin, *C. botulinum* toxin etc.
	Biotoxins	Ciguatoxin, shellfish poisoning, histamine (red meat fish)
	Chemical contaminants	Heavy metals (Hg, Cd, Pb) dioxins, PCBs, etc.

Source: FAO 2009 [16].

histamine poisonings are still occurring [18, 19]. Small decentralized fishery supply chains, inadequate cold storage chain facilities and lack of food safety knowledge are the main reasons.

Tetrodotoxin. Fish poisoning deaths caused by the consumption of wild puffer fish [20–22] has long been reported and is related to the poor safety knowledge of consumers [23]. Puffer fish toxin is also present in other species. In March 2013, in Zhanjiang, 22 people ate poisonous goby. An investigation revealed that tetrodotoxin was consumed from Batocera bare forehead goby (*Yongeichthys criniger*), often mistaken for "jumping fish" [24]. Today, due to natural resource depletion, poisoning from the consumption of wild puffer fish is rare. China's artificial breeding technology safeguards consumers from the risk of puffer fish poisoning [25].

Marine biotoxins. Nassarius (Nassariidae) is a typical cause of food poisoning. Since first reported in 1967, there have been many poisoning cases from the consumption of snails [26, 27]; these incidents have intensified since 2001 [28–30]. Also, an increase in the consumption of imported fish has led to reports of further poisoning incidents from ciguatera. Ciguatera is a reef fish toxin that can cause poisoning in humans. It occurs in the Pacific Ocean, the West Indian Ocean, the Caribbean Sea and South China's coastal areas of tropical and sub-tropical waters, these being the world's major ciguatera endemic regions [31]. Major outbreaks of coral fish food poisoning used to occur in Hong Kong [32]. Through the international trade in coral and wild fish, which have been introduced gradually into the Chinese mainland market via high-end restaurants and gourmet menus, Chinese consumers [33] have suffered from frequent ciguatera poisoning. These ciguatera fish are found in coral reef areas inhabited mainly by foraging fish, many belonging to endangered and protected species. The best protective measure appears to be changing the consumer's concept of desirable seafood.

Statistics show that in China, consumption of toxic puffer fish and shellfish (shellfish poisoning) is the main cause of animal food poisoning [34].

32.2.1.2 Infection

Viral infection. Viruses are the leading cause of food-borne illness from shellfish. Marine-related viruses affecting humans are passed on by human contact during production. The most common food-borne viruses related to shellfish consumption are norovirus and hepatitis A virus.

During the New Year period of 1988 a large number of sea clams entered Shanghai market without hygienic and microbial inspections. The cumulative incidents between 19th January and 18th March amounted to 292 301 cases and 11 deaths [35]. A later epidemiological investigation confirmed that raw clam virus was the cause of this large-scale outbreak [36]. Back in 1979, scientists had conducted field research and found a clear correlation between raw clam and a hepatitis epidemic [37]. Unfortunately, this outbreak failed to capture public attention. Even when more than 30 000 cases of hepatitis were diagnosed from eating raw clam during the 1983 New Year period, also in Shanghai, there was little public awareness. Epidemiological findings made it clear that health management was important in monitoring water quality at source, as well as in capture and farm cultured areas. Finally, in 1988, a hepatitis A outbreak affecting 300 000 eventually resulted in a reaction [38]; the public were made aware of the hazards of consuming contaminated raw seafood and government officials adopted measures for the control of seafood distribution and food safety management.

Parasites. The most typical aquatic parasite is harboured by the snail, *Ampullaria gigas Spix*. An incident in June 2006, in Beijing, led to diagnoses of angiostrongyliasis caused by ingesting undercooked snails. Between 24 June and 24 September, Beijing had a total of 160 cases of clinically diagnosed angiostrongyliasis [39]. The social impact of this food-borne parasitic infection caused great concern to Chinese society. The major food-borne parasitic diseases are caused by consuming: fish infected with Clonorchis trematodes, snails infected with angiostrongyliasis, crabs with paragonimiasis infection, meat infected with swine taeniasis, cysticercosis disease and trichinosis, etc. [40], the first three being found in marine species. This has had a direct impact on the increasingly popular trend of consuming raw fish [41]. China's first known outbreaks of angiostrongyliasis infection occurred in 1997, due to the consumption of undercooked, infected apple snails [42]. In 2002, there was also an outbreak in Fuzhou due to infected snails (*Achatina fulica, Babylonia*) [43]. However, because of geographical isolation, these particular outbreaks did not lead to any social concern. The Beijing incident following the other two, finally alerted consumers, the media, enterprises and regulatory authorities, who have finally learnt the lesson of food safety [44, 45].

Pathogens. Vibrio parahaemolyticus is a major cause of food poisoning in areas where seafood is consumed. The *V. parahaemolyticus* infection is usually caused by eating raw fish or shellfish. Epidemiological characteristics of bacterial food poisoning in coastal provinces indicate mainly *V. parahaemolyticus*, whilst consumers from inland provinces are infected with *Salmonella* [46]. In China, the main organisms causing most food poisoning incidents [47 are *Salmonella and E. coli*, as well as other enteric pathogens, such as *Staphylococcus*, botulism and other food-based pollutants.

32.2.2 Aquatic Food Safety Incident Review

We can safely say that the Chinese government began to recognize that the seriousness of aquatic food safety was not due to outbreaks of food-borne illnesses alone. In the 2000s, media coverage on successive rejections overseas of Chinese aquaculture products due to drug residues, gradually attracted national attention. This, coupled with controversies regarding food safety, meant the pressure to secure safe Chinese food reached unprecedented heights.

32.2.2.1 Chloramphenicol Event

In early 2001, chloramphenicol (2–5 ppb) was detected above the safety limit of 1 ppb in Chinese frozen shrimp, which had been exported to the EU (European Union). Subsequently, chloramphenicol residues were also detected in China's frozen shrimp products in other EU member states. The EU subsequently issued the 2002/69/EC resolution, effective from January 31, 2002, prohibiting imports from China of food of animal origin or animal feed products. In 2002 alone, the financial loss of China's exports to the EU amounted to 600 million US dollars. This effect also spilled over into other export markets [48].

The positive outcome of this event was to promote the modernization of Chinese veterinary management. The list of prohibited drugs in aquaculture and aquatic product quality standards were revised and quality control began to work in aquaculture industry processes. An Aquatic Production Safety Action Plan strengthened the quality of fish feed additives, as well as quality management. This change was not limited to the fishing industry, the entire agricultural supply chain management also benefitted. After 10 years of effort, monitoring systems have been established nationally and internationally for the control of veterinary drug residues. The implementation of this national initiative effectively ensures the safety and control of food from animal origins.

32.2.2.2 Turbot Event

Turbot (*Scophthatmus maximus*) is a valuable commercial fish species originating from the Atlantic coast of Europe. The species was introduced into China in 1992, and into the coastal province of Shandong in 1999 for factory farming practices. By 2005 the entire Chinese eastern coastal region was engaged in turbot farming: from the nursery to breeding, marketing and distribution. The output value for farming enterprises was more than 4 billion yuan [49]. On 17 November 2006, the Xinmin Evening News reported that "Results from sampling 30 pieces of turbot showed that all exceeded drug residue limits". This news immediately caused public panic, affecting both the prosperous farming industry and consumers. It was a devastating blow, particularly for the Shangdong farmers. However, the positive effects of this incident were to alert consumers and the media, as well as encourage regulatory authorities to be more systematic in control mechanisms [50, 51].

32.2.2.3 Other Residue Events

Around 2005 drug residues found in the main breeding species of export aquaculture products: eels, crabs, shrimp, catfish and perch, and so on. caused an enormous furor; residues included antibiotics and malachite-green-based drugs [52, 53]. This occurrence reinforced the public's negative attitude towards farmed aquatic seafood. Moreover, in addition to antibiotics and malachite green, varieties of other agricultural residues were found, such as the pesticide endosulfan and herbicides [54, 55].

32.2.3 Aquatic Product Quality and Safety System Development

32.2.3.1 Growth Amidst the Export Barrier Storm

In China, the quality and food safety control of raw materials for aquatic products is the responsibility of the Ministry of Agriculture. The following review highlights the development process for the quality and safety aspects of aquatic primary production. When China entered the "fish sufficiency" stage (see Section 32.1.1) the problem of preserving the freshness of fish became evident. Before the 1980s, 10% of the catch was spoilt [56] and with the construction of cold storage in fishing ports, chilling facilities improved significantly. Also, onboard chilling of the catch was gradually implemented and hence, catch quality improved greatly [57–60]. At the same time, the aquatic products processing industry became the focus of fisheries development [61].

The development of the quality and safety of aquatic and other agricultural products, as well as their processing for export are closely related. In the 1980s, earnings from fisheries stimulated the export of processed aquatic products [62–64]. In fact, the fish processing export trade was initiated by Chinese prawns (*Penaeus chinensis*). For almost 10 years the prawn strengthened the fish processing industry. With the decline of coastal fishing, the processing of imported product has been included as one of the country's strategy plans [65]. In the early 1990s, shrimp disease outbreaks hit the entire shrimp (*Penaeus chinensis*) supply chain; the vibrant fish processing industry was in crisis. However, the timely influx of large quantities of Russian pollock gave the Chinese aquatic product processing industry a new lease of life and thus came the second era in the rapid development of the processing trade. Since the introduction of the Ninth Five Year Plan (1996–2000) the aquatic products processing trade has developed rapidly, exports have increased significantly [66] and China has gradually become a global economic sea fish processing center. The processing of eel, cultured South American prawns (*Penaeus vannamei Boone*) and tilapia as export products has added to the expansion phase of this flourishing industry. Concurrently, the international market has also gone through several phases of improvement in fishery and food safety regulations and the complete chain of Chinese aquatic products quality and safety management system mechanisms has been gradually consolidated.

The early stages of the aquatic products processing industry coincided with major changes in the international food safety management system. The 1980s proved a watershed for the quality and safety of aquatic products [67], the internationally developed markets changed from a passive end product testing process to proactive prevention and control, and from fragmented control of the supply chain to whole-chain traceability management. The emerging Chinese aquaculture industry encountered the global food safety management change. With one mishap after another, the industry continued to improve and accumulate experience, in other words, under international market rules the industry was forced to change from a non-existent to a well-built quality and food safety management system.

Initially, inadequate hygienic control of aquatic export products was the issue, so the export control department issued compulsory registration and hygiene standards for the processing industry [68]. Then, due to frequent residue infringements, with the assistance of the export market trade, an inspection and control service was set up to screen primary animal products [69]. China formally joined the WTO in 2001, a time when China's export trade in aquatic products was in its most prosperous period. As a member state of WTO under the TBT and SPS rules, the Chinese fish processing industry is enjoying the benefits of fair trade, but also continues to encounter technical difficulties in the export trade. It is noteworthy that in the constant fluctuation in exports, the industrial-chain-related industries are progressing towards a scientific and standardized management business model, whilst public awareness of food safety has gradually awakened. In retrospect, apparent crises have inadvertently promoted the maturity of China's supply chain management of aquatic products; from the early passive struggle to cope with requirements or penalties of export markets, to the gradual improvement of monitoring mechanisms, through to the establishment of a national quality and safety control system to implement preventative management control.

32.2.3.2 Development of the Primary Production Management System

In theory, food-borne illnesses that cause direct harm to consumers should be of major concern to the public. However, apart from the vociferous snail incident, most reports of fish poisoning have not caused widespread or persistent concern. Since the number of cultured fish residue events in the 2000s, consumers have shifted their focus from a positive "fish and health" attitude to the skeptical perception of "fish as unsafe", resulting in an entrenched, irrational fear of consuming seafood.

There are two aspects of antibiotic and chemical residues. Firstly, the basic scientific research and management systems lagged behind the development of the fisheries industry, and secondly, when China became a WTO member, the adoption of the technical requirements under TBT and SPS rules led to well-developed detection analysis technology being introduced. The short term impact of the "residue storm" was forceful; not only did it result in trade embargos, but it also shocked consumers. The positive outcome, however, is that the development and modernization of aquaculture industry management has been accelerated (Table 32.2).

Table 32.2 The evolution and progress of related laws and regulations in the quality and safety control of aquatic production in China.

Laws and regulations		**Implementation date**
Basic laws		
Order of the President of the People's Republic of China (No. 38)	Fisheries Law of the People's Republic of China (2004 Revised) (1986, enacted; 2000, first revision)	2004
Order of the State Council (No. 404)	New«Veterinary Drug Regulations»2004 (1987 enacted)	2004
Order of the People's Republic of China (No. 49)	Agricultural Products Quality and Safety Law of the People's Republic of China	2006
Order of the President of the People's Republic of China (No. 9)	Food Safety Law of the People's Republic of China	2009
Primary production domestic aquatic products		
Ministry of Agriculture	Veterinary Drug Manufacturing Practice (Trial)	1989
Ministry of Agriculture	China Veterinary Pharmacopoeia (Version 1)	1990
Ministry of Agriculture	Implementation Details of Veterinary Drug Manufacturing Practices (Trial)	1994
Ministry of Agriculture	Animal and Animal Origin Food Residue Monitoring Program of People's Republic of China and Official Sampling Procedures (Farming issue (No. 8, 1999))	1999
Ministry of Agriculture	China Veterinary Pharmacopoeia (Version 2)	2000
Order of the Ministry of Agriculture (No. 4)	Management of Aquatic Offspring and other laws and regulations	2001
Order of the Ministry of Agriculture (No. 11)	Veterinary Drug Manufacturing Practices (referred to as Veterinary Drugs GMP)	2002
Ministry of Agriculture	List of Banned Veterinary Drug Compounds for Food Animals (Farming issue (No. 1, 2002))	2002
Ministry of Agriculture	Pollution-free food: safety limits of fishery feed (NY 5072-2002)	2002
Order of the Ministry of Agriculture (No. 31)	Aquaculture Quality and Safety Regulations	2003

(Continued)

Table 32.2 (Continued)

Laws and regulations		**Implementation date**
Ministry of Agriculture	China Veterinary Pharmacopoeia (Version 3)	2005
Ministry of Agriculture Bulletin (No. 1224)	Feed Additive Safety Use Practice	2009
Order of the Minister of the MOA (No. 16)	Animal Medical Management Approach	2009
Order of the Minister of the MOA (No. 17)	Veterinary Practice Management Measures	2009
Order of the Minister of the MOA (No. 18)	Rural Veterinary Management Practices	2009
Order of the Minister of the MOA (No. 19)	Animal Pathogenic Microorganisms (viruses) Collection Management Measures	2009
Ministry of Agriculture Bulletin (No. 1521)	China Veterinary Pharmacopoeia (Version 4)	2010
Order of the Ministry of Agriculture (No. 2, 2013)	Regulation of Prescribed Veterinary Drug and Non-Prescribed Veterinary Drug	2013
Ministry of Agriculture Bulletin (No. 2066)	Regulation of Prescribed Veterinary Drug Product Labelling and Instructions	2013
Ministry of Agriculture Bulletin (No. 2002)	Veterinary Drug Product Instruction Templates	2013
Order of the Ministry of Agriculture (No. 3, 2013)	Decisions on amending the "Registered Veterinarian Management Approach"	2013
Imported Aquatic Products and Processed Aquatic Products (AQSIQ)		
Order of the President of the People's Republic of China (No. 67)	Import and Export Commodity Inspection Law of the People's Republic of China (1989, enacted; 2002, first revision)	2013
Order of the President of the People's Republic of China (No. 53)	Entry and Exit Animal and Plant Quarantine Law of the People's Republic of China (1991, enacted)	2009
Order of the AQSIQ (No. 135)	Regulation of Import and Export of Aquatic Products Inspection and Quarantine	2011
Order of the AQSIQ (No. 145)	Regulation for Registration of Imported Food Foreign Production Enterprises	2012
AQSIQ Bulletin (No. 625, 2013)	Implementation Details of Regulation for Registration of Imported Food Foreign Production Enterprises	2014
Notice of the AQSIQ	Notice on Further Strengthening Inspection and Quarantine of Imported Chilled Seafood	2014

Source: Kow and Liu 2016 [109].

In 2003, realizing the urgency of improving the quality and safety of aquaculture products to protect the ecological environment and consumers, the Ministry of Agriculture issued the "Quality and Safety of Aquaculture" regulations. These comprehensively and systematically regulated all aspects of aquaculture production: farm water quality, fish culture processes, breeding, feeds, use of chemicals and drugs, purification and sanitation, and so on. Thereby, China moved into a new phase of quality and food safety control for the management of aquaculture [70]. Another important advance was the *China Veterinary Pharmacopoeia*, the first edition of which was formulated in 1985. The Ministry of Agriculture progressively revised the 1990, 2000, 2005 and 2010 editions [71, 72]. The 2015 edition is currently being revised [73, 74].

It is noteworthy that the increase in Chinese consumers' demand for imported aquatic products has led the State Administration of Quality Supervision, Inspection and Quarantine, to continually introduce (in place since 2011) "Inspection and control of the importation and export of aquatic products", "Import food product business registration regulations", "Catalog of registered businesses importing food product" and "Imported food production enterprises registered outside the implementation catalog" and "Further notice on improved inspection and quarantine supervision for imported chilled seafood" to enhance the food safety of imported seafood for Chinese consumers.

32.3 Current Status

From the most recent data available [13], China has the greatest farmed fish food production in the world (62% of world total), is ranked the highest by value (14%) for exporting fish and fishery products and the third highest (13%) for importing. Yet, China's food safety is still considered a continuing global problem [75]. The Chinese government is tackling the problem relentlessly on several fronts. These include amending the Food Safety Law, issuing the Twelfth Five-Year Plan, introducing the Food Safety Focus Work Arrangements, upgrading veterinary drug standards and tightening import controls.

32.3.1 The Food Safety Law

The Chinese Food Safety Law was first promulgated in 2009. The China Food and Drug Administration (CFDA), the new food safety authority, was created by China's 12th National People's Congress (NPC) in May 2013. A draft of the amended Food Safety Law was released for public comment in October 2013, soon after its inception. The draft contained six main sections, which included the implementation of regulatory reform to enhance enforcement authority at local government level, more stringent obligations for manufacturers, innovative inspection systems, such as unannounced inspections, and a compulsory food safety liability insurance system. The draft also introduced the certification of food safety regulators and health food products [76, 77].

During 2014, approximately 5000 comments and suggestions were received from the public and stakeholders, which have resulted in over 30 research projects being assigned to relevant institutes, more than 30 workshops and seminars being convened and many more consultations conducted in the field. Subsequently, a second amended draft was submitted to the NPC in December 2014. The second draft included additional regulations for the management of food storage and transportation, as well as genetically modified foods [78]. The amended Food Safety Law finally came into force on 1 October 2015 [79] and is considered the most stringent food safety law in the history of China [80]. At the time of writing, this new law has been in place for less than 3 months and has been met with skepticism in the media [81].

In comparison, food safety regulations in the major Western countries evolved more than two decades ago. In the US the "black book", a guide for the food industry, was published in 1949 by the Food and Drug Administration (FDA). Guides provide means by which the regulatory agency can influence industry practices without having to mandate specific standards; they can also be updated more easily, according to industry needs. In 2010 the FDA Food Safety Modernization Act (FSMA) was introduced, which adopted a more pro-active approach to food safety issues and was more "science-based" regarding safety concerns. The five key areas of the FSMA include preventive controls, inspection and compliance, imported food safety, response (food recalls) and enhanced partnerships (between food agencies).

The European Union (EU), founded post-war in 1957, marked its 50 years of food safety in 2007 [82]. The first Food Hygiene Rules were adopted in 1964 and were limited to requirements for fresh meat. Further hygiene legislation for fishery products and other food groups was developed over the following decades. The Commission's White Paper on Food Safety was only published in 2000 and marked an important milestone for EU policy, with an entirely new approach of applying the rules "from farm to fork". The UK (which joined the EU in 1973) introduced its own Food Safety Act in 1990, followed by the Food Standards Act in 1999. Shortly before celebrating 50 years of food safety, in 2006 the EU implemented new Food Hygiene Regulations and the Food Standards Agency (FSA) of the UK published its first National Food Control Plan in that same year [83].

The food regulatory system in Australia is multi-jurisdictional, encompassing the Australian and New Zealand governments, the states and territories of Australia and local governments. Food Standards Australia and New Zealand (FSANZ) under the Australia New Zealand Food Standards Act 1991 is responsible for setting standards, developing and maintaining the Australia New Zealand Food Standards Code. The standards are based on risk analysis and are consistent for both domestic and international food products. The third of the four chapters in the Code solely addresses food safety, whilst the final chapter covers primary production and processing standards. It is interesting to note that the Primary Production Standards for seafood were developed first, since this was considered the most perishable commodity and hence required the most stringent rules.

China, a late-comer on the scene, has the advantage of benefiting from the experience of other countries.

32.3.2 The Twelfth Five-Year Plan 2010–2015

The Twelfth Five-Year Plan for 2010-2015 for National Food Safety Standards in China was issued by the Ministry of Health [84]. Subsequently, the Ministries of Commerce and Finance selected 20 large- to medium-sized companies to develop traceability systems for the circulation of meat and vegetables, with a view to gradually expanding these to other food products. It was envisaged that by 2015 seafood products would be included in these traceability systems and also that large-scale cross-region cold chain logistical distribution centers would be initiated by the Government [85]. Agricultural product cold-chain logistics are essential to ensure food safety.

This plan also had the daunting task of integrating some 5000 food-related standards, as well as upgrading food hygiene and quality control [86, 87].

32.3.3 Food Safety Focus Work Arrangements

In April 2014 the State Council [88] issued the Food Safety Focus Work Arrangements for that year. Nine areas were targeted to control food safety, starting with environmental factors, such as water pollution, the use of illegal pesticides and veterinary drugs in aquaculture farms, and the processing of dead livestock. The Council also made amendments to the food safety management practices in small-scale and village food businesses, as well as the sale of unsafe food to schools and online. In short, law enforcement agencies are now required to monitor and severely punish any kind of criminal activity in the area of food safety.

32.3.4 Veterinary Drug Standards and Quarantine Inspection Control of Imported Seafood

The first edition of the Veterinary Drug Standards was published in 1990 by the Department of Agriculture and the standards have been constantly upgraded and scrutinized over the last two decades. The latest fourth edition was published in 2010 (Table 32.2). As mentioned in Section 2.3.2 above, the fifth edition is due to be published in 2015 [73, 74].

As mentioned previously, China is ranked third in the world for importing fish and fishery products. Demand increased almost fourfold between 2002 and 2012 from US$ 2198 million to US$7441 million [13]. In order to protect the health of consumers, in 2013 the Chinese Quarantine and Inspection Services required compulsory registration of seafood importers, as well as the upgrading of inspection and quarantine measures for imported aquatic products. The new rules were implemented in 2014 (Table 32.2).

32.4 Gaining Consumer Confidence on Food Safety

The world has seen the remarkable growth of the global fish trade over the last three decades, which makes seafood safety issues even more important. Developing countries play a major role in the international fish trade [89]. This is especially relevant for China, which ranked highest in value worldwide for the export of fish and fishery products. For the domestic market, aquatic products account for more than 20% of the total animal protein source [13].

Many food safety practitioners nationally and internationally have made recommendations on how to gain consumer confidence, especially in the light of unsafe food exported from China over the last few years. Some of these suggestions are listed below (Table 32.3). The background information for more significant factors, international standards, inspection and certification, is given in the following sections.

Table 32.3 Suggestions from food safety practitioners.

Recommendation	Reference	Year
Adoption of international standards	International perspectives on food safety and regulations: A need for harmonized regulations: perspectives in China [87]	2014
	US expert: implementation of new Food Safety Law is even more challenging [90]	2015
Traceability	Food Safety Management in China: A Perspective from Food Quality Control System [85]	2013
	Comparison of Global Food Traceability Regulations and Requirements [91]	2014
Food recall	Food Safety Management in China: A Perspective from Food Quality Control System [85]	2013
Inspection	Policies and practices for aquaculture food safety in China [92]	2010
	Regulatory and policy control on food safety in China [93]	2012
	Food Safety Management in China: A Perspective from Food Quality Control System [85]	2013
Certification	United States Import Safety, Environmental Health, and Food Safety Regulation in China [94]	2012
	Food Safety Management in China: A Perspective from Food Quality Control System [85]	2013
Law enforcement	Regulatory and policy control on food safety in China [93]	2012
	The national food safety control system of China: A systematic review [95]	2013
	Can China convince consumers it is serious on food safety? [77]	2014
	Food Safety in China: A Comprehensive Review [96]	2014
Information transparency	The national food safety control system of China: A systematic review [95]	2013
	Food Safety in China: A Comprehensive Review [96]	2014
	Governing China's food quality through transparency: A review [97]	2014
Social responsibility	Confronting the crisis of food safety and revitalizing companies' social responsibility in the People's Republic of China [98]	2013
Consumer awareness	Chinese Consumers' Demand for Food Safety Attributes: A Push for Government and Industry Regulations [99]	2012
	Research report: Public risk perception of food additives and food scares. The case in Suzhou, China [100]	2013
Exchange with international community	Food Safety in China: A Comprehensive Review [96]	2014

Source: Kow and Liu 2016 [109].

32.4.1 International Food Code and Standards (Codex Alimentarius)

The Codex Alimentarius was set up in 1963 as a joint instrument of the United Nations FAO and the WHO. Apart from the protection of consumer health it also has the objective of ensuring fair practices in international food trade by developing common food safety standards. In 1991, the FAO/WHO adopted a horizontal approach to setting standards, that is, consumer participation and the codex standards, guidelines and code of practice became a reference for food safety in the World Trade Organization (WTO) Agreement in 1995 on Sanitary and Phytosanitary Measures (SPS Agreement). There are 11 general subject working Codex Committees and the Codex Committee on Fish and Fishery Products (CCFFP) is one of the 12 commodity working committees, which has Norway as the host country [101]. Currently there are about 350 standards, guidelines and codes of practice and about 4% (27) of these are fishery related. These standards are all available in English, French and Spanish, whilst only 14 are available in Chinese. Arabic and Russian are two other available languages [102].

32.4.2 Inspection and Certification, Basis of Food Safety Management: FSSC 22000

Many food safety control measures and standards have been evolved to enhance consumer confidence in food safety. The Global Food Safety Initiative (GFSI) was founded in 2000 with the main objectives of benchmarking food safety management schemes and harmonizing different international food safety standards. Since 2010, the GFSI fully recognised FSSC 22000, a new global Food Safety System Certification standard. Other major global standards for food safety management systems are the British Retail Consortium (BRC), first introduced in 1998, Safe Quality Food, 1995 (SQF 1995) and the International Food Standard, 2004 (IFS 2004). Organizations that obtain FSSC 22000 certification will meet the requirements of several global retailers, such as Walmart, under a single internationally recognized food safety management system. FSSC 22000 encompasses most comprehensive approaches to a food safety management system for the food manufacturing sectors. The basis of FSSC 22000 is Publicly Available Specification 220 (PAS 220) and International Standard Organization 22000 (ISO 22000) for the supply chain; the latter integrates into other well-established business quality management systems such as ISO 9001, ISO 14001 (environmental standard) and Occupational Health and Safety Standard 18001 (OHSAS 18001) [103]. An important component of FSSC 22000 is the audit process, which runs on a three-year cycle with annual surveillance audits. As a result, re-certification is required every three years. Should the seafood industry in China adopt such a system, it will be a powerful tool for the industry.

The comprehensive food-chain approach advocated by the FAO [88] in drafting a food safety strategy for fisheries and aquaculture is specifically noteworthy: there are five requirements that is, implementation of risk analysis, traceability, harmonization of international quality and safety standards, equivalence in food safety systems and risk avoidance or prevention at source. The FAO technical paper provides sound practical measures for the different levels of stakeholders: government, industry, academia and consumers. For example, government is urged to organize control services, to train personnel for control services, to upgrade control facilities and laboratories, and, importantly, to develop national surveillance for hazards. As for industry, there is also a need to upgrade facilities and train personnel. In addition, it is paramount that the industry implements Good Aquaculture Practices (GAP), Good Hygienic Practices (GHP) and Hazard Analysis and Critical Control Points (HACCP). Academia has the important task of training personnel in the food supply chain and conducting research on quality, safety and risk assessment. In addition, academia should also provide technical support to stakeholders. Finally, consumers need to provide feedback to the rest of the stakeholders by forming advocacy groups.

It can be seen that there is no shortage of recommendations and protocols for the management of food safety for fisheries and aquaculture in China. The government has diligently devised rules and regulations to assist the management of food safety, but the country is still in the early stages of implementing food safety systems. It should be mentioned here that currently there are two tiers of management system operating for aquatic products in China. One system aligns with international food safety requirements for the export market, whilst the second, covering the domestic market, is less stringent and still in its infancy. The products for the export market are relatively trouble free, but this cannot be said for the domestic market [104, 105]. It is human nature to avoid adverse situations and seek secure sources for food, including seafood. However, this could lead to dangerous complacency in the domestic market where unsafe product processing conditions may spill over and affect export market products. Take, for example, the recent scandal of exported berries from China to Australia where more than a dozen people contracted hepatitis A due to direct or indirect sewage contamination of the berries [106]. Although this commodity was not seafood, it is a good illustration of possible future scenarios, i.e. mishaps taking place with well-scrutinised export commodities because basic food safety conditions were infringed.

In the opinion of the authors, future food safety management success lies in total control, commencing from the registration and food safety training of all food businesses to ensure the upgrading of food safety skills and awareness. There are three main gate keepers of food safety management systems: the food business heads or managers, the food safety auditors and the law enforcement agencies [107]. All efforts should be made by the administrators to assist and educate these business managers on food safety rules, regulations and standards. An internationally endorsed food safety auditing system needs to be introduced, with quality auditors to ensure compliance with food law and standards, and lastly, vigilant law enforcement agencies need to be empowered to severely penalize those who deviate, for there can be no compromise in food safety.

References

1 Anon. (1994) Director General Mr. Youzhan Zhuo talked about the name issue in fishery agencies. *China Fisheries*, 8, 3–6 [in Chinese].

2 Chen, D.L. (1998) Rapid development of fisheries in the two decades of reform and opening up. *Guide for Getting Rich by Fishing*, 6, 6–7 [in Chinese].

3 Zhao, Y.X. and Zhang, J.G. (1984) Stop aquatic products "battle". *China Fisheries*, 3, 17 [in Chinese].

4 Chen, D.L. (2002) A review on fisheries in China. *Modern Fisheries Information*, 1, 5–10 [in Chinese].

5 Anon. (1979) Start from adjustment, to boost fisheries as soon as possible (Editorial). *China Fisheries*, 1, 2–4 [in Chinese].

6 Ministry of Agriculture (1984) Husbandry and fishery: production and marketing of aquatic products. *China Fisheries*, 4, 2–3 [in Chinese].

7 She, D.N. (1980) Discussion on the structure adjustment of fishery production. *China Fisheries*, 2, 7–10 [in Chinese].

8 Zhao, Y. (1989) The role of fisheries in the national economy and future measures of aquaculture development. *Modern Fisheries Information*, 4, (2–3), 20–30 [in Chinese].

9 Bureau of Fisheries, Ministry of Agriculture (1995) Fisheries Development Research Report (Part 1). *Fisheries Economy Research*, 1, 12–24 [in Chinese].

10 Guan, R.J. (1989) Rise up in the process of reform: A review on the 40 years' development of aquaculture. *China Fisheries*, 12, 10–11 [in Chinese].

11 Tu, F.J. (1988) Actively accelerate the development of distant seas fisheries. *China Fisheries*, 5, 2–3 [in Chinese].

12 Ministry of Agriculture (2006–2014) *China Fishery Statistics Year Book (2005–2013)*, China Agriculture Press. [in Chinese].

13 Food and Agriculture Organization of the United Nations (2014) *The State of World Fisheries and Aquaculture: Opportunities and Challenges*. Food and Agriculture Organization of the United Nations, Rome, Page 65.

14 Tan, S.S. (2012) The supermarket "cod" illusory. *Science Regimen*, 7, 12–13 [in Chinese].

15 Chen, C.B. (2012) Who can identify the nationality of squid. *Delicacy*, 5 (5),49 [in Chinese].

16 Food and Agriculture Organization of the United Nations (2009). Safety of Fish and Fish Products. http://www.fao.org/fishery/topic/1522/en, (accessed 3 June 2015).

17 Song, W.D. (1985) How to prevent food poisoning from mackerel. *China Fisheries*, 6, 13 [in Chinese].

18 Xi, C.Y. and Miao, Y.Z. (2012) An investigation of histamine poisoning caused by eating mackerel. *Chinese Journal of Health Laboratory Testing*, 7, 1730 [in Chinese].

19 Cui, C.X., Yu, X.J. and Cao, S.S. (2012) Deteriorated mackerel caused acute histamine poisoning in 87 cases. *Preventive Medicine Tribune*, 10, 781–782 [in Chinese].

20 Anon. (1955) Preventing from puffer fish poisoning. *People's Daily* (June 26) [in Chinese].

21 Department of Internal Medicine, Yantai City Hospital (1961) Report of 5 cases of puffer fish poisoning. *Shandong Medical Journal*, 3, 26 [in Chinese].

22 Jin, W.X. and Lu, DX. (1980) Desperate to eat puffer fish. *Food Science and Technology*, 5, 6–7 [in Chinese].

23 Deng, F. and Lai, W.M. (1995) Puffer fish poisoning and preventive measures in Guangdong Province from 1982–1993. *Diet and Health*, 1, 30–31 [in Chinese].

24 Song, Q.H. (2013) Aquatic products food poisoning caused by cloud bare forehead goby in Zhanjiang, Guangdong. *Science of Fish Breeding*, 4, 48 [in Chinese].

25 Li, Q., Liu, J.R., Liu, S.C. and Wang, Y. (2014) The development of a traceability information model in rubripes breeding. *Journal of Dalian Fisheries University*, 29 (5), 502–507 [in Chinese].

26 Ye, L.M., Xu, J.Y., Yan, P. and Song, Q.F. (2008) Studies on toxicity and toxins of Nassarius sp in Ningbo City. *China Preventive Medicine*, 12, 1089–1093 [in Chinese].

27 Shui, L.M., Chen, K., Wang, J.Y. *et al.* (2001) Epidemiological and toxicological characteristics of Nassarius poisoning in Zhoushan City in 1977–2000. *Strait Journal of Preventive Medicine*, 5, 4–7 [in Chinese].

28 Huang, S.G. (2003) Investigation on paralytic shellfish poisoning caused by *Nassarius. Practical Preventive Medicine*, 10 (1), 85–86 [in Chinese].

29 Yu, R.C., Zhou, M.J., Li, A.F. *et al.* (2007) Analysis of toxins in *Nassarius* responsible for two poisoning incidents in China. *Journal of Fishery Sciences of China*, 14 (5), 801–806. [in Chinese].

30 Zhang, N., Su, J., Liu, H.X. and Li, L.F. (2010) Study on the source of toxion in *Nassarius semiplicatus*. *Marine Environmental Science*, 29 (5), 705–707. [in Chinese].

31 Xu, Y.X., Wang, A.H., Hu, R. *et al.* (2012) Studies on Ciguatera toxins in coral fishes along the southern coast of *China*. *China Environmental Science*, 32 (2), 330–336 [in Chinese].

32 Wu, H.L., Zhuang, D.H., Chen, Y.H. and Mou, Y. (2000) Study on the Ciguatoxin fishes in China. *Journal of Shanghai Fisheries University*, 9 (4), 298–307 [in Chinese].

33 Zhao, S.Q., Zhang, K., Fang, Y.X. *et al.* (2006) An overview of current ciguatoxin poisoning situation and laboratory analysis. *South China Sea Fishery Science*, 2(2), 68–70 [in Chinese].

34 Chu, F.J., Ran, L., Ma, L. and Lin, X.H. (2012) Epidemiological analysis of food poisoning incidents reported by the public health emergency events surveillance system in China (2008–2010). *Chinese Journal of Food Hygiene*, 24 (4), 387–389 [in Chinese].

35 Zhou, L.N. (2008) The panic moment in Shanghai 20 years ago. *China News Weekly*, 14, 43 [in Chinese].

36 Zheng, Z., Ye, Y.H. and Jiang, S.Z. (1988) Yellow tornado: interview on Shanghai hepatitis A pandemic. *Chinese Writers*, 5, 85–105 [in Chinese].

37 Yu, S.Z. (1988) Reflection on Shanghai hepatitis A pandemic. *Science*, 4, 285–290 [in Chinese].

38 Kang, L.Y. (1990) Relationship between shellfish and human disease. *Chinese Journal of Public Health*, 8, 369–372 [in Chinese].

39 Beijing Municipal Health Bureau (2006) Report on the first Angiostrongylus Cantonensis, disease happened in Beijing. (October 10), http://sjshb.bjsjs.gov.cn/wsbb/402880ce2ea29170012ea2942aef0663.html (accessed December 2014) [in Chinese].

40 Lin, J.X. (2006) Trends and control strategy of food-borne parasitic diseases. *Strait Journal of Preventive Medicine*, 4, 1–3 [in Chinese].

41 Lin, J.X. (2006) Prevention and control of food-borne parasitic diseases. *Strait Journal of Preventive Medicine*, 5, 77–81 [in Chinese].

42 Xue, D.Y., Ruan, Y.Z, Lin, B.C. *et al.* (2000) Epidemiological investigation on an outbreak of Angiostrongyliasis Cantonensis in Wenzhou city. *Chinese Journal of Parasitology and Parasitic Diseases*, 3, 177–178 [in Chinese].

43 Pan, C.W., Yin, C.H., Tan, F. and Wang, J. (2006) Insight from the group Angiostrongyliasis emergency. *Journal of Pathogen Biology*, 1, 321–323 [in Chinese].

44 Meng, Q.P. and Qian, F. (2006) Snails incident exposed “gray area” in food safety control. Health News (August 25). http://www.ce.cn/cysc/sp/info/200608/25/t20060825_8284313.shtml [in Chinese].

45 Xu, X.W. and Wang, T. (2006) Snails events will change people’s eating habits. China Business Daily (September 12). http://www.foods1.com/content/56080/ [in Chinese].

46 Wang, S.J., Yang, J., Chen, Z.Q. *et al.* (2006) Analysis on 776 incidences of bacterial food poisoning in China from 1994 to 2003. *China Preventive Medicine*, 7 (3)1, 80–185 [in Chinese].

47 Nie, Y., Yin, C., Tang, X.C. and Wang, Z.G. (2013) Analysis of food poisoning characteristics and emergency countermeasures in China from 1985 to 2011. *Food Science*, 34 (5), 218–222 [in Chinese].

48 Xiao L. (2002) The chloramphenicol storm. *China Fisheries*, 7, 12–17 [in Chinese].

49 Ye, J.L. (2006) Thinking of the turbot events. *China Fisheries*, 12, 14–16 [in Chinese].

50 Anon. (2007) Where are the crisis experts. *Agricultural Market Weekly*, 4, 14–16 [in Chinese].

51 Ma, F. and Zhou, Z.X. (2007) Grasp the critical point of food risk reporting: Insight from the turbot event. *Chinese Journalists*, 6, 46–47 [in Chinese].

52 Xiao, L. and Li, Z.L. (2005) About “malachite green”. *China Fisheries*, 8, 6–11 [in Chinese].

53 Zhang, W.B. (2010) Ten years review and thinking of aquatic products quality and safety incidents in China. *China Health Standard Management*, 1(5), 57–61 [in Chinese].

54 Xiao, L., Hu, G.C. and Wang, F. (2006) What “excessive Endosulfan” incidence once again shows? *China Fisheries*, 9, 13–14, 26 [in Chinese].

55 Kang, W.M., Xiao, D.X. and Guo, S.Z. (2007) “Endosulfan residues” alarm sounded again. *China Inspection and Quarantine*, 5, 16–17 [in Chinese].

56 Xu, Y.C. and Zheng, F.L. (1979) Fresh preservation and development of fishing catch in East China Sea. *Journal of Fujian Fishery Science and Technology*, 2, 40–43 [in Chinese].

57 Sun, R.Z. (1987) Status quo and development trend of China’s aquatic products preservation facilities. *Modern Fisheries Information*, 5, 1–4 [in Chinese].

58 Jin, J. (1988) Improve awareness and accelerate the development of fresh preservation and processing of aquatic products. *China Fisheries*, 12, 7–11 [in Chinese].

59 Jiang, Y.C. (1990) Investigation and reflection on the fresh preservation on marine fishery ships. *China Fisheries*, 11, 11–15 [in Chinese].

60 Chen, D. and Kow, F. (2003) China’s seafood processing sector: preparing for the future. *INFOFISH International* (FAO, Kuala Lumpur), 2, 30–35.

61 Anon. (1985) Aquatic products processing and production should be of equal importance (editorial). *China Fisheries*, 3, 2 [in Chinese].

62 Tu, F.J. (1986) Work hard to further develop excellent situation. *China Fisheries*, 10, 2–3 [in Chinese].

63 Zhang, S.S. (1986) Fisheries development for obtaining foreign exchange. *Fujian Forum (Economic and Social Edition)*, 9, 22–24 [in Chinese].

64 She, D.N. (1988) Assess the situation and actively develop export-oriented fisheries. *China Fisheries*, 5, 6–7 [in Chinese].

65 Li, L.Q. (1988) To export processed products made from imported raw materials is a major strategic development of China’s export trade policy. *International Trade*, 1, 7–9 [in Chinese].

66 Che, B. (2002) An analysis on characteristics of aquatic products processing during “Ninth Five Years”. *Chinese Fisheries Economics*, 3, 51–56 [in Chinese].

67 Ababouch, L., Gandini, G. and Ryder, J. (2005) Causes of detentions and rejections in international fish trade, FAO, Fisheries Technical Paper, 473.

68 State Commerce Inspection Administration. (1995) Health practice for the registration of export aquatic products processing enterprises. *China Food Industry*, 10, 44–46 [in Chinese].

69 Ministry of Agriculture. (2002) Commentary report by the Ministry of Agriculture of P.R. China on the "Draft Report for the Residue Control in Live Animals and Animal Products by EC Inspection Mission to China". *Chinese Journal of Veterinary Drug,* 36 (5), 6–10 [in Chinese].

70 Xiao, L. (2003) Chinese aquaculture has entered a new phase of quality management. *China Fisheries,* 9, 5–6,12 [in Chinese].

71 News Office of the Ministry of Agriculture. (2011) News conference on the 2010 edition of "Chinese Veterinary Pharmacopoeia" in effectiveness organized by the Department of Veterinary, Ministry of Agriculture. *Chinese Journal of Veterinary Medicine,* 47 (9), 87–88. [in Chinese].

72 Xu, X.J. (2011) To develop Veterinary Pharmacopoeia of People's Republic of China (2010 Edition) for the perfection of national veterinary drugs standard system. *Chinese Journal of Veterinary Drug,* 45 (8), 1–4 [in Chinese].

73 Anon. (2012) A preparation meeting for the development of the part 1 2015 edition of "Chinese Veterinary Pharmacopoeia" was held in Beijing. *Veterinary Orientation,* 4, 74 [in Chinese].

74 Anon. (2016) A preparation meeting for the development of the part 2 2015 edition of "Chinese Veterinary Pharmacopoeia" was held in Beijing. *Chinese Journal of Veterinary Drug,* 46 (5), 19 [in Chinese].

75 Editorial. (2014) China's food safety: a continuing global problem. *The Lancet,* (August 2–8), 384(10041), 377.

76 State Council. (2013) *People's Republic of China Food Safety Law revised manuscript.* http://baike.baidu.com/view/10986082.htm (accessed December 2014).

77 Ho, B., Shi, C. and Wu, J. (2014) Can China convince consumers it is serious on food safety? *China Business Review*. Review (August 1).

78 State Council. (2014) *People's Republic of China Food Safety Law revised manuscript.* http://baike.baidu.com/view/10986082.htm (accessed February 2015).

79 Xi, J.B. (2015) The Food Safety Laws of the Peoples' Republic of China. *Order of the Chair of the Peoples' Republic of China*. Number 21, 24th April 2015.

80 The most stringent Food Safety Law in history – can it ensure safety of the "tongue tip". 2015. http://www.cqn.com.cn/news/zjpd/dfdt/1049471.html (accessed May 2015).

81 New Food Safety Law is already in force for two months – experts state problems in enforcement. 2015/11/30. http://www.chinacourt.org/article/detail/2015/11/id/1778578.shtml (accessed December 2015).

82 European Commission. (2007) *50 years of Food Safety in the European Union.* Luxembourg: Office for Official Publications of the European Communities. 42 pp.

83 Food Law: Key events. (2015) http://www.foodlaw.rdg.ac.uk/history.htm. (accessed December 2015).

84 Ministry of Health. (2010) *National Food Safety Standards, Twelfth Five-Year Plan. Issue 1.* http://baike.baidu.com/view/8801956.htm (accessed December 2014).

85 Zhou, J. and Jin, S. (2013) *Food Safety Management in China: A Perspective from Food Quality Control System.* eBook. Singapore: World Scientific Publishing Co.

86 Ministry of Health. (2012) *National Food Safety Standards, Twelfth Five-Year Plan. Issue 40.* http://baike.baidu.com/view/8801956.htm (accessed December 2014).

87 Liu, X. (2014) International perspectives on food safety and regulations. A need for harmonized regulations: Perspectives in China. *Journal of the Science of Food and Agriculture,* 94(10), 1928–1931.

88 State Council. (2014) *State Council Announcement No. 20* http://baike.baidu.com/view/13230407.htm?fr=aladdin (accessed May 2014).

89 FAO. (2014) *Assessment and management of seafood safety and quality.* FAO Fisheries and Aquaculture Technical Paper; 2014, Issue 574, pi-432, 452p.

90 US expert: The implementation of new Chinese Food safety laws is even more challenging. 2015/09/29. http://www.qizhong123.com/a/qizhong123-r1x50929n422318334.html (accessed October 2015).

91 Charlebois, S., Sterling, B., Haratifar, S. and Naing, S.K. (2014) Comparison of Global Food Traceability Regulations and Requirements. *Comprehensive Reviews in Food Science and Food Safety.* 13(5), 105–1123.

92 Broughton, E. and Walker, D.G. (2010) Policies and practices for aquaculture food safety in China. *Food Policy* 35 (5), 471–478.

93 Chung S.S. and Wong, C.K. (2012) Regulatory and policy control on food safety in China. *Journal of Epidemiology and Community Health.* 67 (6), 477–477.

94 Nyambok, E. O. and Kastner, J. J. (2012) United States import safety, environmental health, and food safety regulation in China. *Journal of Environmental Health.* 74 (6), 28–34.

95 Jia, C. and Jukes, D. (2013) The national food safety control system of China: A systematic review. *Food Control.* 32 (1), 236–245.

96 Wu, L. (2014) *Food Safety in China: A Comprehensive Review.* Hoboken: Taylor and Francis. 378 pages.

97 Mol, A.P.J. (2014) Governing China's food quality through transparency: A review. *Food Control.* 43, 49–56.

98 Jiang, Q. and Zu, Y. (2013) Confronting the crisis of food safety and revitalizing companies' social responsibility in the People's Republic of China. *Asia Pacific Business Review.* 19 (4), 600–616.

99 Ortega, D.L., Wang, H.H., Olynk, N.J., Wu, L. and Bai, J. (2012) Chinese consumers' demand for food safety attributes: A push for government and industry regulations. *American Journal of Agricultural Economics.* 94 (2), 489–495.

100 Wu, L., Zhong, Y., Shan, L. and Qin, W. (2013) Public risk perception of food additives and food scares. The case in Suzhou, China. *Appetite.* 70, 90–98.

101 List of active Codex Committees. (2015) http://www.codexalimentarius.org/committees-and-task-forces/en/ (accessed December 2015).

102 List of fishery related standards, guidelines and codes. (2015) http://www.codexalimentarius.org/committees-and-task-forces/en/?provide=committeeDetail&idList=17 (accessed December 2015).

103 Sansawat, S. and Muliyil, V. (2010) *Understanding the FSSC 22000 food safety system certification standard.* A white paper on the challenges, impact and opportunities contained in FSSC 22000. SGS. 12 pp.

104 Twelve experts on 2014 food safety major incidents. (2015) http://www.ce.cn/cysc/sp/info/201501/13/t20150113_4331983.shtml (accessed January 2015).

105 Lam, H., Remais, J., Fung, M., Xu, L. and Samuel, S., (2015) Food supply and food safety issues in China. *The Lancet* 381 (9882), 2044–2053.

106 Frozen berries: Consumers face anxious seven-week wait for Hepatitis A diagnosis, (2015) http://www.news.com.au/lifestyle/food/frozen-berries-consumers-face-anxious-seven-week-wait-for-hepatitis-a-diagnosis/story-fneuz8wn-1227224791495 (accessed February 2015).

107 Kow, F. (2015) Enhancing consumers' confidence in quality and safety of food: An Australian perspective, *The Sixth International Forum on Food Safety*, Beijing, China.

108 Liu, J. (2014) *Status quo of China's fishery supply, demand and trade*. Paper presented at *INFOYU-FAO workshop*, Shenzhen, China *April* 2014, 15–16.

109 Kow, F. and Liu, J. (2016) Seafood Industry in China: A Food Safety Perspective. In: Jen, J. and Chen, J. (Eds) *Food Safety in China: Past, Present and Future*. China Science and Technology Press, p. 390–409.

Part 7

New Technology

33

Food Safety Traceability

Yimin Wei[1]*, Boli Guo*[1]*, Hongyan Liu*[1]*, Shuai Wei*[1] *and Jianrong Zhang*[2]

[1] *Institute of Food Science and Technology, Chinese Academy of Agricultural Sciences, Beijing, China*
[2] *Center for Food Safety and Applied Nutrition, Food and Drug Administration, USA*

33.1 Introduction

With globalized economics, it is becoming more frequent to trade food across country and regional borders, which leads to expanding and spreading of all kinds of food safety incidents and hazards. Mad cow disease, foot and mouth disease, avian flu and other zoonotic diseases pose a grave threat to food safety and human health, causing serious economic losses for food industries and causing social panic at the same time. In order to reduce the losses caused by such serious zoonotic diseases, as well as to ensure food safety, many countries have started to implement food safety traceability systems. The European Union has the most advanced regulations on food traceability. EU regulation No. 178/2002 requires all food products within the European Union be trackable and traceable, starting from January 1, 2005, otherwise they cannot be sold [1]. The EU also has other regulations targeting specific food products, such as regulation No. 1224/2009 for fisheries and aquaculture products, No. 931/2011 for food business operators with respect to food of animal origin, regulation No. 1337/2013 on the country of origin or place of provenance for fresh, chilled and frozen meat from swine, sheep, goats and poultry, and Nos. 1829/2003 and 1830/2003 relating to the authorization, labelling, and traceability of genetically modified food and feed. The US Food and Drug Administration (FDA) requires all US and foreign facilities engaged in food production, processing, packaging, or managing people or animal consumption must register with the FDA prior to 12 December 2003 to ensure food safety tracking and tracing. The Bioterrorism Act of 2002 (BT Act), and the record keeping requirements contained within, represented a major step forward in the implementation of a product tracing system for FDA-regulated food products. This Act requires a paper trail documenting food distribution, to allow determination of the source of contamination in the event of a foodborne illness outbreak. The FDA Food Safety Modernization Act (FSMA) was signed into law by President Obama on 4 January 2011. It aims to ensure the US food supply is safe by shifting the focus of federal regulators from responding to contamination to prevention. Section 204 of the FSMA requires the US FDA to develop additional recordkeeping requirements for high-risk foods, to improve their traceability. These mandates

Food Safety in China: Science, Technology, Management and Regulation, First Edition.
Edited by Joseph J. Jen and Junshi Chen.

are yet to be published and are expected to be available in draft format in the coming years. During September 2011, the FDA tasked the Institute of Food Technologists (IFT) to conduct two pilot studies on traceability to explore and demonstrate methods for rapid and effective tracking and tracing of food, including types of data that are useful for tracing, ways to connect the various points in the supply chain, and how quickly data can be made available to the FDA. The final report was released in 2013, with findings from pilot projects, and the IFT's recommendations to the FDA for improving the tracking and tracing of food. In September 2013, the IFT launched the Global Food Traceability Center (GFTC), a science-based, not-for-profit public-private partnership. It brings together key stakeholders in the food system to collaborate on traceability solutions and serves as an authoritative source for food traceability.

There are no specific traceability regulations for food commodities in Canada other than for livestock. However, traceability of processed food products is verified through proper packaging and labelling in accordance with the Consumer Packaging and Labelling Act and regulations, and specific regulations for individual food commodities, as well as the Food Safety Enhancement Programs (FSEP) for meat products. The Japanese Ministry of Agriculture, Fishery and Foresty (MAFF) has mandates under its beef traceability program for domestic beef, requiring that an assigned number is carried through from the birth of the cow, to the processed carcass at the abattoir, and the label on the final packaged product, or its invoice. The rice law enacted in 2009 requires record keeping of transactions of rice and grains, and informing consumers and business partners of origin information, to allow prompt identification of the distribution route when a problem occurs.

A food traceability system has been recognized as an effective measure for food safety supervision and management, and it is an important tool to monitor the entire "farm to table" process, to ensure the fast recall of "problematic food", to reduce economic losses, and to improve consumer confidence.

The Chinese government gives high priority to the development of a food safety traceability system. Considerable work has been carried out, from the establishment of regulations, laws and policies, through development of traceability technology platforms, and research and development, to industrial demonstrations.

33.2 Legal Regulations

The State Administration for Quality Supervision, Inspection and Quarantine started the implementation of the "Exit Aquatic Products Traceability Rules (Trial)" in June 2004, which requires the export of aquatic products and its raw materials be labelled in accordance with the provisions of the regulations. The export of aquatic products can be traced back from the finished products to the raw materials by the labels on the outer packaging. China implemented the "Agricultural Product Quality Safety Act" in November 2006. Article 24 of the Act states: that agricultural producers and rural specialized cooperative economic organizations should establish agricultural production records, and record accurately the following: (1) the name, source, usage, dosage and start/end date of agricultural inputs; (2) animal diseases and the occurrence and prevention of plant pests; (3) date of harvest, slaughter or harvest. Agricultural production recordss shall be kept for two years, and the fabrication of agricultural production records is prohibited. The state encourages other agricultural producers to establish agricultural production records. The Ministry of Agriculture (MOA) issued "NY / T1430-2007 Agricultural Product Production Site Encoding Rules" [2] and "NY / T1431-2007 Agricultural Product Traceability Coding Guidelines" [3] in 2007. The coding terminology and definitions for the production sites of agricultural products, segregation principles for production units, coding rules for production sites, the unit data requirements for production sites, and coding principles of agricultural products were all regulated. In 2010, the MOA released NY/T1940-2010 Tropical Fruits Categorizing and Coding System [4], which sets out the principles and methods of classification of tropical fruits, the coding method, and classification codes. Articles 36 to 39 of the 2009 Food Safety Law clearly defined that food production enterprises should establish a record system for food ingredients, food additives, and food-related products. Warehouse inspections need to faithfully record the name, size, quantity, supplier name and contact information, and purchase date of food ingredients, food additives, and food-related products. They should establish a food factory inspection records system, check food factory inspection certificates, and the food safety situation, and accurately record the food name, specification, number, production date, production batch number, inspection certificate number, name and contact information of purchasers, sales date, and so on. Food enterprises should establish a food purchase inspection record system to faithfully record the food name, specification, quantity, batch number, shelf life, supplier name and contact information, purchase date, and so on. These inspection records should be truthful and the retention period should not be less than two years. In 2015 the newly revised "Food Safety Law" Article 42 clearly states that the national government should establish a full traceability system for food safety. The food producers should be in accordance with the provisions of this law, and develop a food safety traceability system to ensure food traceability. The state encourages food producers and traders to use systems to collect information, retain production and management information, and establish food safety traceability systems. Clearly, Chinese laws and regulations on the developments of food safety traceability systems are maturing.

State regulations have specific requirements for food safety traceability system development. The 2012 Central One document proposed to strengthen overall coordination of food quality and safety supervision, by strengthening the inspection and traceability systems. The 2013 Central One document proposed the full implementation of regulatory responsibility from the farm to the table, to improve the quality and safety traceability system for agricultural products. It also required rigorous production and operation management for agricultural inputs, and required a record system be established for agricultural inputs. The 2014 Central One document proposed to establish the most stringent food safety regulatory system covering the whole process, to support food traceability systems, and to establish rigorous production management systems. The 2015 Central One document also demanded the improvement of agricultural product quality and food safety standards, increasing the regulatory capacity of agricultural product quality and food safety at the county level, and establishing a full traceability information platform with internet sharing capability for agricultural product quality and food safety. The 2014 State Central Rural Work Conference also proposed to control strict use and misuse of agricultural inputs, and to establish a sound agricultural and food safety traceability system, and establish a unified national agriculture and food traceability information platform as soon as possible.

33.3 Food Safety Traceability System

In order to ensure food safety for the 2008 Olympics, Beijing city government established the Olympic food safety monitoring and traceability system in January 2008, with a full monitoring system "from farm to table" for all the food supplies, especially poultry and meat. Starting with a pilot study first with specific focuses, the Ministry of Commerce and Ministry of Finance supported pilot studies in 35 cities in three batches starting from 2010, created a meat traceability system, explored and utilized the information technology management market, strengthened food safety system management, and modernized the circulation of commodities. By the end of 2013, the development of the meat product traceability system had made remarkable achievements. The first 10 cities completed the development of traceability system covering a total of 3007 companies, including 134 slaughterhouses, 77 wholesale markets 1766,631 large supermarket chains, and 399 consumer group units. It covered mechanized slaughterhouses, wholesale markets, all large- and medium-sized supermarket chains in the inner cities, improved the safeguarding capability for food safety and quality, and enhanced the scientific level of modernization and industrial management in the supply chain.

Beginning in 2004, the MOA started a traceability system pilot project. The State formally established a reclamation agricultural product quality traceability system in 2008. By the end of 2013, the number of companies participating in this system reached 283, and reached 350 by the end of 2014. The system covered 28 provinces and autonomous regions, excluding Tibet, Qinghai, and Shanxi Provinces. The system covered major agricultural products such as grains, vegetables, fruits, tea, poultry and meat products, eggs, fish, milk, seeds, and other agricultural inputs, wine, and other processed products. The system introduced numbers of traceable products with good brand reputations and safety capabilities to domestic and foreign markets.

Agricultural inputs traceability regulation is an important measure to protect agricultural product quality and safety from source. The Institute of Food Science and Technology in the Chinese Academy of Agricultural Sciences developed the "Agricultural Inputs Traceability Management System," funded by the agricultural product quality and safety supervision project, "Agricultural inputs Information Platform Development and Demonstration," initiated by the MOA, which has been demonstrated and implemented in Hubei, Hunan, Fujian, Shandong, Jiangsu, Jiangxi, Anhui, Guizhou, Inner Mongolia, and Liaoning provinces. The system combines government regulation, business management, and consumer purchase query capabilities, and addresses interfacing problems between different regional information management systems, to achieve a national regulation network.

The food traceability system is a complicated systematic project involving multiple agencies and disciplines, with appropriate technology support. Barcodes, RFIDs, information technology and network-based electronic data tracking technology are the foundations for the whole food chain traceability system. The food system has a variety of food products, long industrial chains, and diverse information to be recorded; how to guarantee the authenticity of the traceability information is the key to the development of a food traceability system. Therefore, the system also requires good faith and science-based regulatory support. Currently, scientific research is focusing mainly on the identification of plant and animal species and varieties, as well as technologies to identify the origins of products.

33.4 Food Traceability and Verification Technology

33.4.1 Plant and Animal Species Identification Technology

With the "horse meat scandal," "adulterated meat," and other food safety issues arising, animal and plant species identification technology is a growing concern in the academic world. At present, the approaches that can quickly and accurately identify animal species are mainly based on proteomics, chromatography, spectroscopy, and DNA fingerprinting techniques.

33.4.1.1 Proteomics Analysis

Proteins (enzymes, myoglobin, etc.) have been widely used for species identification. The electrophoretic patterns of water-soluble proteins are often associated with animal breeds. Starch gel electrophoresis, polyacrylamide gel electrophoresis, agarose gel electrophoresis and isoelectric focusing electrophoresis are used to separate water-soluble proteins. Gel electrophoresis for protein detection has detection limits between 0.1% and 1%, depending on the clarity of the protein bands. Microimmunological techniques, such as Western blots and enzyme-linked immnosorbent assays are mainly used for microanalysis of solid-phase target proteins, and can also be used for the quantitative analysis of animal species. The detection limits depend on the meat varieties in the animal products tested: for pork ≤1%, poultry and beef ≤2%, and lamb ≤5% [5]. With specific protein band patterns, animal species, varieties, and strains can be distinguished.

33.4.1.2 Chromatography/Spectrometry Methods

Chromatography and spectroscopy metabolomic methods can identify the authenticity of animal and plant products, and classify the different varieties. Rochfort *et al.* (2013) used nuclear magnetic resonance (NMR) and gas chromatography mass spectrometry to analyze water-soluble and fat-soluble metabolic component in Australian blue mussels (*M. galloprovincialis* varieties) and New Zealand green mussels (*P. canaliculus* varieties). They found significant differences in the metabolic components from different varieties [6]. Son *et al.* (2008) used ^{1}H NMR to identify the origins of different varieties of grapes [7]. Wu *et al.* (2015) differentiated and identified nectar honey from difference sources in China (canola flower honey, acacia honey, vitex honey, and date honey), with a correct classification rate of 100% [8]. Lu *et al.* (2014) used UPLC-MS and chemometric methods and successfully identified Chinese Goji samples from different areas and different species [9].

33.4.1.3 DNA Fingerprinting Methods

In recent years, DNA analysis techniques have been widely used in food research and control. DNA testing for identification of food varieties was originally used for hybridization analysis using specific DNA probes [10, 11]. Currently, the polymerase chain reaction (PCR) is used as a key technology for species identification in food and feed products. It is often used with restriction fragment length polymorphism (PCR-RFLP) on plants and animals to identify varieties of food [12]. Random amplified polymorphic DNA-polymerase chain reaction (RAPD-PCR) based on single strand conformation polymorphism (SSCP) has also been used to distinguish between different species of animals and plants in the studies [13].

Many specific PCR systems may be used to analyze plant and animal species, and the analytical accuracy of these techniques is very high. They can be used for species identification of complex samples, even for processed foods (e.g. sterilized), and the system is very effective. Typically, the detection limit of DNA technology is ≤ 0.1%, depending on the detection limit of the PCR method used [5]. Currently, the method has been used for grapes [14], seafood [15], cereals [16], and other food varieties.

33.4.2 Food Origin Identification Technology

With environmental pollution, food safety incidents, as well as the protection of product origin and other issues, the origins of food products have become an issue of great concern for the government authorities and consumers. On one hand, food production sites are closely associated with disease outbreak and pollution events. When food safety incidents occur, the region of occurrence is identified for traceability of food origin as the basis for tracing the harmful source. On the other hand, the nutritional quality of food and its origin are closely related; tracing the food origin will facilitate the implementation of regulations and the protection of products from particular reas.

Currently, the EU has three labels for special regional product certification, namely Protected Designation of Origin (PDO), Protected Geographical Indication (PGI), and Traditional Specialty Guaranteed (TSG) [17]. The previous China State Administration of Quality and Technical Supervision issued a Geographical Origin Protection Regulation in August 1999, indicated the initial establishment of a geographical indication protection system with Chinese characteristics. In June 2005, the State Administration of Quality Supervision, Inspection and Quarantine promulgated the Provisions for the Protection of Geographical Indication Products, based on the merging of the existing Geographical Origin Protection Regulations and the Place of Origin Symbol Regulations, showing further development of the geographical indication protection system in China. In February of 2008, the MOA implemented a list of Geographical Indications of Agricultural Management Practices [18]. China has now approved more than 2000 kinds of geographical indication products.

In the real food production and supply chain process, driven by economic interests, some unscrupulous traders will use the fake products to replace genuine ones and replace good quality products with bad quality products, as well as using products from other regions to replace geographical origin products. They deceive the consumers, create food safety problems, and cause confusion in the geographical origin product market, thus harming consumer interests and impacting the credit system for industry and enterprises. Food origin and validation technologies have been developed in recent years, providing technical support for the food chain traceability system and regulation of these geographical origin products.

33.4.2.1 Traceability Technology Principles and Applications for Food Origin

Food origin and validation technology explores the characteristic indicators of food from different regions. Stable isotope fingerprints, mineral element fingerprints, IR fingerprints, and organic ingredient fingerprints are often used in food traceability and validation research. The traceability principles and characteristics of different technologies vary.

Stable isotope fingerprinting. In nature, organisms constantly exchange substances with the environment. The compositions of ^{13}C / ^{12}C, ^{15}N / ^{14}N, ^{2}H / ^{1}H, ^{34}S / ^{32}S and other stable isotope in the body are impacted by climate, environment, types of biological metabolism and other factors. Natural fractionation will occur and cause differences in natural isotopic abundance from different sources. This difference carries information about environmental factors, reflects the environmental conditions in which an organism lives, and can be used as a "natural fingerprint" to distinguish between substances from different regions [19]. Therefore, isotopic fingerprints are the natural labels of all creatures, closely related to the growth environment of an organism, and does not change with chemical additives. It provides food traceability in a scientific, independent, and immutable way, with identity authentication information flowing throughout the food chain. Isotopic analysis has the advantages of a simple sample preparation procedure for pre-testing, small sample size, high precision, and fast analysis speed.

For tracing food origin, isotopes of H, O, C, N, S, B, and Sr are commonly used. Most research has focused on analyzing the differences in isotopic compositions of foods from different geographical regions, analyzing the isotopic compositions of food components, the correct classification rate of isotopic indicators of food origin, establishing a traceability database, and mapping the traceability of food origin. Chinese experts and scholars have confirmed the effectiveness of the use of stable isotopes for food products such as beef [20], lamb [21], fish [22], and blackcurrant [23].

Mineral element fingerprinting. Affected by geology, water, and soil environmental factors, differences exist in the composition and content of mineral elements of soils from different regions, thus leading to unique and characteristic mineral element fingerprint profiles for organisms growing in different regions. The key to using mineral elements fingerprinting for tracing food origin is to pick out the fingerprint of stable elements associated with the food growing region from a wide variety of elements [24]. Sun *et al.* (2011) collected 99 lamb meat samples from five regions in China and determined 25 elements (Be, Na, Mg, Al, K, Ca, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, As, Se, Mo, Ag, Cd, Sb, Ba, Tl, Pb, Th, and U) using ICP-MS, as well as analyzing the meat samples using a combination of PCA, CA, and LDA. They also selected 12 kinds of elements (Be, Cr, Mn, Fe, Cu, Zn, As, Sb, V, Ba, Ni and Na) using stepwise analysis to develop a discriminating model; this model crosschecked five geographical samples, with an overall correct classification rate of 88.9% [25]. Luo Ting *et al.* (2008) collected 28 green tea samples from four provinces in China (Anhui, Zhejiang, Sichuan, Guizhou) and tested mineral elements such as K, Ca, Cu, Fe, K, Mg, Mn, P, Zn, etc. by inductively coupled emission spectrometry; better distinction between different regions was achieved by analyzing clusters of the first five main components [26]. Zhao (2011) collected 240 wheat samples randomly from four regions in China (Hebei, Henan, Shaanxi, Shandong) for two consecutive years, analyzing for 15 elements (Be, Na, Mg, Al, K, Ca, V, Mn, Fe, Cu, Zn, Mo, Cd, Ba and Th) using ICP-MS. After using multivariate statistical analysis, it was found that the mineral element fingerprint method still had great potential for identifying wheat origin, despite differences in year of harvest, genotype, and field management, which may impact the element content [27].

Infrared spectroscopy. Infrared spectroscopy (IR) refers to a spectrograph which reflects the results of interactions between infrared radiation and the substance analyzed, with the wavelength or wave number as the horizontal axis, and the strength or other properties as functions of the wavelength as the vertical axis. The wavelength range of infrared rays can be roughly divided into near-infrared (0.8–2.5μm), mid-infrared (2.5–25μm) and far-infrared (25–1000 μm.) By using spectrophotometric analysis for spontaneous emissions from substances, or by stimulating emissions using infrared radiation, an infrared emission spectrum is obtained. When the infrared ray absorbed by the substance is analyzed, and infrared absorption spectrum is obtained. Organisms from different regions are affected by the external environment; some differences exist in their chemical composition and structure, thus creating characteristic spectra with different spectral shapes, absorption locations, or intensities [28]. This principle can be used to distinguish and confirm the origin of food. Currently, Chinese scholars have used IR for food origin identification purposes for beef [29], lamb [30], tea [31], wheat [32], West Lake lotus root starch [33], and loquat [34] products.

Organic composition fingerprinting technology. Affected by temperature, humidity, sunshine, rainfall, soil, and other factors, the compositions and contents of organic substances such as fat, protein, carbohydrates, vitamins, and flavors in the same type of food from different regions are significantly different, and have unique fingerprint features. By conducting screening studies of organic compounds in food products that characterize different regions, fingerprinting technology for organic composition can be set up for food source identification.

Yang, Zhuanying and *et al.* (2012) compared and analyzed the sugar composition of litchi fruits from six different regions in the Guangdong Province, such as Guangzhou City, Yangjiang City, Dongguan City, Maoming City, Taishan City, and Longhai. The results showed that the micro-environment and management level of the product region can affect the sugar composition of litchi fruit [35]. Ma, Yiyan *et al.* (2013) tested vitamin C, vitamin E, soluble solids, total acid, and total sugar content of 93 kiwi fruit samples from three main production areas, Zhouzhi and Mei Counties in Shaanxi Province, and Muchuan County in Sichuan Province, and Yongshun County in Hunan Province. The analysis of variance results showed that there were significant differences in the organic compositions with different fingerprints for the kiwi fruits. The kiwi fruits from Zhouzhi and Mei Counties, had the highest vitamin C, but the lowest vitamin E, soluble solids and total sugar contents. The kiwi fruits from Muchuan County, had the highest vitamin E, soluble solids, and total sugar contents, while the total acid content was the lowest. The kiwi fruits from Yongshun County, had the highest total acid content and lowest vitamin C content [36]. Qiu, Qiang *et al.* (2012) planted three high-fat, three high-protein and three common cultivars in six ecological zones of Jilin from 2005 to 2007, respectively, then analyzed the different soybean cultivars to determine the impacts of different ecological effects and conditions on the quality of fat content, protein content, and total fat/protein from each region. The results showed that there were significant differences between the different ecological ranges on the compositions of fat, protein, and total protein and fat [37]. In their research on food animal origin, Chen, Bijun, *et al.* (2012) found significant differences in the compositions and contents of fatty acids in beef from four major beef-producing areas, Jilin, Ningxia, Guizhou, and Hebei. The saturated fatty acid (SFA) content of beef from Jilin and Hebei was significantly higher than from Guizhou and Ningxia, The C16:1 and C18:1 mono-unsaturated fatty acids (MUFAs) in Ningxia beef were significantly higher than other regions. The a-C18:3, C20:5, and polyunsaturated fatty acid (PUFA)-n3 contents in beef from Guizhou and Hebei were significantly higher than those from Jilin and Ningxia. By using discriminate analysis, it was reported that a-C18:3, C14:0, C17:0, SFAs, and MUFAs could potentially be five indicators for tracing the geographical origin of beef. The overall discrimination rate was 82.0% for their four geographical origin tests [38].

33.4.2.2 Trends in Food Origin Traceability Technology

With global attention focusing on food safety and product identification technology, food origin traceability technology has been researched and applied to a variety of animal and plant products. In recent years, there have been two new trends in the technological development of food origin traceability. One is the use of a strontium isotope for food origin traceability becoming increasingly prominent. The other is the analysis of changes in these traceability indicators during processing, to screen effective indicators for processed products, and expand the scope of application for geographical origin technology. Zhou *et al.* (2015) collected beef samples from three different provinces in China, and tested changes in $\delta^{13}C$, $\delta^{15}N$, and $\delta^{2}H$ in the meat after three processing methods: boiling, frying, and grilling. They found a significant impact on $\delta^{2}H$ but no significant impact on $\delta^{13}C$ and $\delta^{15}N$ [39].

33.5 Problems and Recommendations

33.5.1 Problems

First, there is a lack of uniform traceability standards and guidance, different traceability system architecture has been developed by different ministries, and tracing information cannot be shared and interconnected. The newly revised “Food Safety Law” proposed to establish a national food safety traceability system. To be in accordance with the provisions of this law, food producers shall develop safety systems to ensure that food is traceable. The state encourages food producers and traders to use information systems to collect and retain production and management information. Currently, there is a lack of standards and guidance on how to establish a food safety traceability system and of a state authority responsible for its development and management; there is also no unified platform to manage a food traceability system. Due to the lack of uniform technical standards and specifications, the current tracing methods are confusing, thus the current traceability system has become a common labeling system.

Second, there is a lack of product coding and basic information databases, making it difficult to collect food traceability information. In comparison with developed countries, China’s overall agricultural production is small in scale, with less intensification, standardization, and organization. About 200 million small-scale farmers in China use their own pesticides, veterinary drugs, and have their own fertilizer programs. Their production is in accordance with their wishes. Their products will be transferred between more than 30 million small traders, through the local intermediary and wholesale markets, before they are delivered to the consumers’ tables. In order to achieve traceability in agricultural cultivation, growth, and other aspects of production, information about fertilizers, pesticides, veterinary drugs, and production management, amongst others, must be fully recorded. Most Chinese farmers are not highly educated and have low professional knowledge. The high costs of information recording are not welcomed by these farmers. Moreover, there is a lack of coding system and basic information databases for seeds, pesticides, veterinary drugs, fertilizers, and other agricultural inputs. Also, most products are not marked with a traceability code when they are shipped out of the plant, thus making the collection of source traceability information difficult.

Third, traceability systems, GAP, and HACCP are not yet closely related. Guidance for a traceability system for enterprise quality and safety management is not strong, the cost of establishing a system is high, and enterprises lack the motivation to develop and implement it, so the application rate of traceability systems is low. Currently, most of the food traceability indicator systems are not screened or determined by GAP and HACCP, so that key traceability information is missing. When food safety issues occur, the traceability system cannot play its role. Moreover, the development cost of a food safety traceability system is relatively high: companies not only need to invest in software and hardware requirements, but also need to send professionals to help them record the information, use the system, conduct regular staff training, change management concepts, and develop the habit of recording complete production process information. Businesses not only have to spend money, but a lot of manpower is needed, and implementation is a lengthy process. For low-margin industries such as the food industry, such a high cost of investment can be overwhelming for many small businesses. If the government does not have favorable policies, and the market doesn't have much demand, food companies have no incentive to invest in food traceability systems.

Fourth, consumer awareness of the value of a traceability system is low. Consumers are ultimately buyers of traceable foods, and their willingness to pay for traceable food determines the enthusiasm of food companies for implementing a food traceability system. Although the system will increase certain costs for the enterprises, if consumers are willing to pay higher prices, manufacturers could produce traceable food at certain scales to meet this consumer demand, thus improving system utilization, reducing marginal cost for traceable products, and creating larger revenue. Conversely, if consumers are not willing to pay more for traceable food, and the government does not provide favorable policies and economic support, then enterprises are unlikely to want to adopt the system. A survey found that consumer awareness of food traceability is very low. Another survey also showed that only 3% of people are very familiar with the food traceability system; even in Beijing city where there is a relatively high awareness of food traceability, some pilot house staff did not have good understanding of it.

Last, information security and anti-counterfeit measures are poor. Information technology provides tools for developing a food traceability system, but like any other network information, there is the danger of viruses like Trojan horses and other erosion, resulting in the loss of information, theft, tampering, and other issues. There is also the risk of leakage of confidential business information. For bar codes and two-dimensional codes, risks include wrong coding, copying, and piracy. Currently, cases occur frequently where two-dimensional code scanning either does not come out or food traceability information does not exist. Consumers have more concerns about whether the source of information is true and reliable and the information complete, than trusting the traceability system itself.

33.5.2 Recommendations

33.5.2.1 Establish and Improve Food Safety Traceability Regulations and Standards

The government's primary responsibility in the development of food safety traceability systems is to enact laws and regulations, develop standards and related management systems, and to provide guidance on implementation measures in agricultural production, processing, and distribution. Currently, the regulations on implementation of food traceability are not comprehensive, there is a lack of traceability guidance, of specifications, and standards for recording information in a traceability system. Lack of coding specifications, basic information databases, and other prerequisite work for agricultural inputs and food need to be further strengthened and improved.

33.5.2.2 Strengthen Top-Level Design and Build a Unified Information Platform

A food safety traceability system requires interoperability information, unified planning, and design from the national level. It requires a unified information-recording system, a unified modular design, a unified data format, and a unified coding system to achieve the goal of communication and exchange of information through the whole food chain.

33.5.2.3 Promote the Standardization and Intensification of Agricultural and Food Industries

Agricultural production in small-scale operations, dispersed cultivation, and diversification of sales channels are the main factors restricting food traceability system development. Chambers of Commerce, agricultural production cooperatives, and leading enterprises of agricultural production and distribution need to play a leading role of driving food traceability systems and applications.

33.5.2.4 Establish a Scientific Supervision and Management System and Promote an Enterprise Credit System to Guarantee the Authenticity of Traceability Information

The key to food traceability development is to guarantee continuity and authenticity of the traceability information in the chain. We need to continue to research and develop key traceability information indicators, such as origin, variety, species, and other identification and validation technologies, strengthen the supervision and management system, and continue to improve and perfect the integrity of the system in food companies, preventing phenomena such as false information and traceability tampering, to improve the credibility of traceability information.

33.5.2.5 Enhance the Information Level of Agricultural Infrastructure

The cost of developing a food traceability system is relatively high, but agricultural and food industries have relatively low profits, which results in a lack of motivation to develop a traceability system among agricultural and food production enterprises. Governments need to provide special funds to support the development of demonstration bases for food traceability systems, while providing hardware, equipment, technical training, and other support for food businesses or other industrial organizations.

33.5.2.6 Strengthen the Convergence of Networking Technology and Traceability System Development

Sensors, big data, cloud computing, RFID, and other advanced technologies need to be taken full advantage of to exploit their intersection with agricultural product logistics and food traceability, solve technical problems such as timely information collection, transmission, and exchange in food traceability, and ultimately interact with the relevant parties.

33.5.2.7 Intensify Publicity Efforts to increase Consumer Awareness

The government should publish objective information through the media, in order to strengthen information release on food safety where consumers have concerns. They should publish timely information on the status and applications of food traceability systems, increase the consumer awareness level and interest in traceable food, and expand market demands for traceable food, thereby reducing cost pressures and encouraging more enterprises to actively develop food traceability systems.

A food traceability system is a comprehensive system that needs advancement from government regulation, corporate integrity, and consumer recognition. With larger agricultural production scales and speeds, and the rapid development of information technology, food traceability systems in China will embark on a new stage in 2020.

References

1 European Commission. Regulation (EC) No. 178/2002 of the European Parliament and of the Council. 2002,1.

2 The Ministry of Agriculture and the People's Republic of China. Rules for coding of agricultural land. Beijing, The Ministry of Agriculture and the People's Republic of China, 2007 [in Chinese].

3 The Ministry of Agriculture and the People's Republic of China. Guideline for numbering of agricultural products for tracing. The Ministry of Agriculture and the People's Republic of China, 2007 [in Chinese].

4 The Ministry of Agriculture and the People's Republic of China. Classification and coding for tropical. The Ministry of Agriculture and the People's Republic of China, 2010 [in Chinese].

5 Schwägele, F. (2005). Traceability from a European perspective. *Meat Science*, 71(1), 164–173.

6 Rochfort, S. J., Ezernieks, R., Maher, A.D., *et al.* (2013). Mussel metabolomics: Species discrimination and provenance determination. *Food Research International*, 54(1), 1302–1312.

7 Hong-Seok, S., Ki Myong, K., Frans, V. D. B., *et al.* (2008). ^{1}H nuclear magnetic resonance-based metabolomic characterization of wines by grape varieties and production areas. *Journal of Agricultural and Food Chemistry*, 56(17), 8007–8016.

8 Zhaobin, W., Lanzhen, C., Liming, W., *et al.* (2015). Classification of Chinese honeys according to their floral origins using elemental and stable isotopic compositions. *Journal of Agricultural and Food Chemistry*, 63(22), 5388–5394.

9 Lu, W., Shi, H., and Yu, L. (2015). Exploratory chemometric analysis on source of origin and cultivar of Chinese Wolfberries using liquid chromatograph-mass spectrometric and flow injection mass spectrometric (FIMS) fingerprints. In: The Chemical Sensory Informatics of Food: Measurement, Analysis, Integration (ed. B. Guthrie, J. Beauchamp, A. Buettner, B. K. Lavine). ACS Symposium Series. eBook.

10 Chikuni, K., Ozutsumi, K., Koishikawa, T., and Kato, S. (1990). Species identification of cooked meats by DNA hybridization assay. *Meat Science*, 27(2), 119–128.

11 Wintero, A. K., Thomsen, P.D., and Davies, W. (1990). A comparison of DNA-hybridization, immunodiffusion counter current immunoelctrophoresis and isoelectric focusing for detecting the mixture of pork to beef. *Meat Science*, 27, 75–85.

12 Verkaar, E. L. C., Nijman, I. J., Boutaga, K., and Lenstra, J. A. (2002). Differentiation of cattle species in beef by pcr-rflp of mitochondrial and satellite DNA. *Meat Science*, 60(4), 365–369.

13 Weder, J. K. P. (2002). Identification of plant food raw material by RAPD-PCR: legumes. *Journal of Agricultural and Food Chemistry*, 50(50), 4456–4463.

14 Sumiko, N., Kazutomo, H., Nobuhito, M., and Ken'Ichi, O. (2007). Novel preparation method of template dnas from wine for pcr to differentiate grape (vitis vinifera l.) cultivar. *Journal of Agricultural and Food Chemistry*,55(25), 10388–10395.

15 Pascoal, A., Barros-Velázquez, J., Ortea, I., *et al.* (2011). Molecular identification of the black tiger shrimp (*Penaeus monodon*), the white leg shrimp (*Litopenaeus vannamei*) and the Indian white shrimp (*Fenneropenaeus indicus*) by PCR targeted to the 16s RRNA MTDNA. *Food Chemistry*, 125(4), 1457–1461.

16 Prins, T. W., Dijk, J. P. V., Hoef, A. M. A. V., *et al.* (2010). Towards a multiplex cereal traceability tool using padlock probe ligation on genomic DNA. *Food Chemistry*, 118(4), 966–973.

17 Todea, A., Oroian, I., Holonec, L., *et al.* (2009). Legal protection for geographical indications and designations of origin for agricultural products and foodstuffs. *Bulletin of University of Agricultural Sciences and Veterinary Medicine Cluj-Napoca. Horticulture*, 66(2), 463–466.

18 Ministry of Agriculture of People's Republic of China. Measures for the administration of geographical indications of agricultural products. Beijing: Ministry of Agriculture, P.R.C, 2007 [in Chinese].

19 Guo, B.L., Wei, Y.M., and Pan, J.R. (2007). Progress in the application of isotopic fingerprint analysis to food origin traceability. *Transactions of the Chinese Society of Agricultural Engineering*, 23(3), 284–289 [in Chinese].

20 Guo, B. L., Wei, Y. M., Pan, J. R., and Li, Y. (2010). Stable C and N isotope ratio analysis for regional geographical traceability of cattle in China. *Food Chemistry*, 118(4), 915–920.

21 Sun, S.M., Guo, B.L., Wei, Y.M., and Fan, M.T. (2010). Analysis of stable carbon and nitrogen isotope compositions and geographical origins of sheep tissues. *Scientia Agricultura Sinica*, 43(8),1670-1676 [in Chinese].

22 Ma, D.H., Wang, X.C., Liu, L.P., and Liu, Y. (2012). Application of hydrogen stable isotope in Chinese export tilapia geographical origin traceability. *Food and Machinery*, 3(1), 5–7 [in Chinese].

23 Li, Q., Chen, L., Ding, Q., and Lin, G. (2013). The stable isotope signatures of blackcurrant (Ribes nigrum L.) in main cultivation regions of china: implications for tracing geographic origin. *European Food Research and Technology*, 237(2), 109–116.

24 Franke, B. M., Gremaud, G., Hadorn, R., and Kreuzer, M. (2005). Geographic origin of meat: Elements of an analytical approach to its authentication. *European Food Research and Technology*, 221(3), 493–503.

25 Sun, S., Guo, B., Wei, Y., and Fan, M. (2011). Multi-element analysis for determining the geographical origin of mutton from different regions of China. *Food Chemistry*, 124(3), 1151–1156.

26 Luo, T., Zhao, L., and Hu, X. S. (2008). Study on characteristic analysis of mineral elements in green tea and discrimination based on origin. *Food Science*, 29(11), 494–497 [in Chinese].

27 Zhao, H., Guo, B., and Wei, Y. (2011). Determining the geographic origin of wheat using multielement analysis and multivariate statistics. *Journal of Agricultural and Food Chemistry*, 59(9), 4397–4402.

28 Liu, L., Cozzolino, D., Cynkar, W. U., *et al.* (2008). Preliminary study on the application of visible–near infrared spectroscopy and chemometrics to classify Riesling wines from different countries. *Food Chemistry*, 106(2), 781–786.

29 Li, Y., Wei, Y.M., Pan, J.R., and Guo, B.L. (2009). Determination of geographical origin of beef based on FTIR spectroscope analysis. *Spectroscopy and Spectral Analysis*, 29(3), 647–651 [in Chinese].

30 Sun, S. M., Guo, B.L., Wei, Y.M., and Fan, M.T. Application of near infrared spectral fingerprint technique in lamb meat origin traceability. *Spectroscopy and Spectral Analysis*, 31(4), 937–941 [in Chinese].

31 Zhan, M. L., Li, Y., Wei, Y. M., *et al.* (2008). Determination of the geographical origin of tea by FT-IR spectroscopy analysis and pattern recognition technique. *Journal of Nuclear Agricultural Science*, (06), 829–833 [in Chinese].

32 Zhao, H. Y., Guo, B.L., Wei, Y.M., *et al.* (2011). Identification of geographical origins of wheat with discriminant analysis by near infrared spectroscopy. *Scientia Agricultura Sinica*, 44(7), 1451–1456 [in Chinese].

33 Xu, L., Shi, P.T., Ye, Z.H., *et al.* (2012). Rapid geographical origin analysis of pure West Lake lotus root powder (WL-LRP) by near-infrared spectroscopy combined with multivariate class modeling techniques. *Food Research International*, 49, 771–777.

34 Fu, X., Ying, Y., Zhou, Y., and Xu, H. (2007). Application of probabilistic neural networks in qualitative analysis of near infrared spectra: determination of producing area and variety of loquats. *Analytica Chimica Acta*, 598(1), 27–33.

35 Yang, Z. Y., Wang, H.C., Zhao, Z.C., *et al.* (2012). A comparative study on the sugar accumulation and composition in the Aril of Litchi from different regions. *Chinese Journal of Tropical Crops*, 32(8):1398–1402 [in Chinese].

36 Ma, Y.Y., Guo, B.L., Wei, Y.M., *et al.* (2013). Discrimination of kiwi fruit according to geographical origin ased on organic compound fingerprint analysis. *Scientia Agricultura Sinica*, 46(18), 3864–3870 [in Chinese].

37 Qiu, Q., Liu, X.H., Zhang, W., *et al.* (2012). Ecological analysis on oil and protein content of soybeans in Jilin province. *Soybean Science*, 31(5), 749–752 [in Chinese].

38 Cheng, B. J. (2012). Study on beef geographical origin traceability based on fatty acid fingerprint analysis. Masters thesis, Beijing: Chinese Academy of Agricultural Sciences [in Chinese].

39 Zhou, J., Guo, B., Wei, Y., *et al.* (2015). The effect of different cooking processes on stable C, N, and H isotopic compositions of beef. *Food Chemistry*, 182, 23–26.

34

New Techniques for Genetically Engineered Organism Analysis

Litao Yang, Dabing Zhang and Sheng Quan

School of Life Science and Technology, Shanghai Jiao Tong University, China

A genetically engineered organism (GEO) is an organism whose genetic composition has been altered by genetic engineering technologies. GEOs are engineered to acquire new stably inherited traits such as insect resistance, herbicide resistance, and drought resistance, etc. In China, the government not only invests heavily in the research and development of GEOs, but also makes stringent administrative regulations to strengthen their biosafety assessment. In 2001, the Chinese government issued the Regulation on the Safety Management of Agricultural Genetically Engineered Organisms, defining basic concepts and scope of agricultural GEOs, which include transgenic plants, animals, microorganisms, and their derivatives that are used in agricultural production.

34.1 Status of GEO Commercialization

Since the introduction of the world's first commercialized agricultural GEO, the transgenic tomato "FLAVR SAVR" in 1994, the global planting area of GEOs has increased drastically. According to the data issued by the International Service for the Acquisition of Agri-biotech Applications (ISAAA) [1], the planting area of GEO crops had reached more than 180 million hectares by the end of 2014, increasing more than 100-fold since 1996. In 2014, A total of 59 countries and regions have planted or adopted GEO crops and their derivatives, including 319 GEO events from 25 crop species. The GEO planting areas in the top 10 countries all exceed a million hectares. The US is number one with 69.5 million hectares, or 40.8% of the global GEO planting area; second is Brazil, which takes up 21.5%; third is Argentina with 14.03%; fourth is Canada with 6.8%; fifth is India with 6.3%; and sixth is China with 2.4%, or 4 million hectares (Table 34.1). Klumper *et al.* carried out comprehensive statistical analysis of a total of 147 known GEO research projects in the past 20 years and concluded that the application of transgenic technology has reduced the usage of chemical pesticides by 37%, improved crop yields by 22%, and increased the income of farmers by 68% [2]. These conclusions are consistent with a report by PG Economics, in which it is believed that GEOs have brought more than 100 million dollars worth of economic benefits in the past 16 years. This transgenic technology has brought not only significant economic benefits to

Food Safety in China: Science, Technology, Management and Regulation, First Edition.
Edited by Joseph J. Jen and Junshi Chen.

Table 34.1 Planting of GEOs in the 10 main countries in 2014.

Rank	Country	Planting area (million hectares)	Species of GEOs
1	America	69.5	Maize, bean, cotton, rapeseed, sugarbeet, clover, papaya, pumpkin
2	Brazil	36.6	Bean, maize, cotton
3	Argentina	23.9	Bean, maize, cotton
4	Canada	11.6	Rapeseed, maize, bean, sugarbeet
5	India	10.8	Cotton
6	China	4.0	Cotton, papaya, aspen, tomato, pimento
7	Paraguay	3.4	Bean, maize, cotton
8	South Africa	2.9	Maize, bean, cotton
9	Pakistan	2.8	Cotton
10	Uruguay	1.4	Bean, maize

Source: ISAAA report [1].

farmers, but also great environmental benefits. To summarize, transgenic technology can promote food safety, enhance agricultural productivity and economic benefits for farmers, reduce environment deterioration, slow down climate change, and reduce greenhouse gas emission from agricultural production.

34.2 The Worldwide Regulations for GEO Labeling

While transgenic technology has been used globally, many countries and regions have also strengthened the safety management of GEOs in the meantime. To date, there are more than 50 countries and regions that have issued and executed voluntary or mandatory GEO labeling regulations, with specific GEO content labelling thresholds (Table 34.2) [3]. The threshold is traditionally expressed as the weight ratio of GEO to non-GEO content, such as in processed soybean products [4]. The European Union (EU) has announced that the threshold used for GEO labeling is based on GEO to non-GEO genome DNA copy ratio [4]. However, there is no direct correlation between the copy number of genomic DNA and the weight of actual plant material, which may generate discrepancies when using genomic DNA copy and weight ratios as calibrators for GEO quantification.

34.2.1 Mandatory Labeling Regulations

Most countries and regions, such as the EU, Japan, Korea, and Russia have mandatory GEO labeling regulations with specified thresholds. Feed/food products with GEO contents exceeding established thresholds are mandated to be labeled. EU regulation Nos. 1829/2003 and 1830/2003 set up a traceability system for GEO feeds/foods with a threshold of 0.9%. In China, there is no specified threshold for GEO labeling, and instead 17 feed/food products made from five crops (tomato, cotton, soybean, maize, and canola) are required to be labeled if there is any detectable GEO content [5]. In

Table 34.2 Identification management of GEOs in the major countries in the world.

Identification category	Thresholds	Meaning of the ratio	Countries/districts
Mandatory labeling	No data	–	China, India
	0.9%	Ratio of DNA copy number	EU, Ireland. Russia
	1%	Quality percentage	Australia, New Zealand, Brazil, Croatia, Saudi Arabia, Israel
	2%	Quality percentage	Chile, Norway
	3%	Quality percentage	Korea, Malaysia
	5%	Quality percentage	Japan, Taiwan of China, Thailand, Indonesia
Voluntary labeling	Not set	Quality percentage	America, Argentina, South Africa
	5%	Quality percentage	Hongkong of China, The Philippines, Canada

Japan, the Ministry of Agriculture, Forestry, and Fisheries (MAFF) issued announcement No. 517 in March 2000, defining the threshold for GEO ingredients labeling as 0.5%. The Korean Government implemented a mandatory GEO labeling regulation with a threshold of 3% from March 1, 2001.

34.2.2 Voluntary Labeling Regulation

Several countries have issued voluntary labeling regulations for GEOs, such as the US, Canada, Argentina, and Brazil. In the US, GEOs and their products are administrated according to the Federal Food, Drug, and Cosmetic Act, and only GEOs with obvious differences from their conventional counterparts or potentially allergenic should be labeled. The GEO labeling regulations in Canada are quite similar to those in the US [6].

34.2.3 Low Level Presence

Low level presence (LLP) refers to the unintended presence of minute amounts of unapproved genetically modified (GEO) events in imported products. LLP has become a key issue in global GEO regulations. In the Codex Guideline for the Conduct of Food Safety Assessment of Foods Derived from Recombinant-DNA Plants (CAC/GL 45-2003, Annex III 2008), LLP is defined as low levels of recombinant DNA plant materials that have passed a food safety assessment in one or more countries, but may on occasion be present in food in importing countries in which the food safety of the relevant recombinant-DNA plants has not been determined [7]. In the future, incidents of LLP are expected to increase significantly since many new GEO events are being developed throughout the world. In the EU, the threshold of LPP is set at 0.1% [9]. In China, LLP is often detected in imported soybean and maize samples, such as the LLP of GEO maize event MIR162 and MON89034 in the past that caused significant economic losses in international trade [8].

34.3 Currently Used Methods and Technologies for GEO Analysis

In general, differences between a GEO and its non-GEO counterpart can exist in DNA, transcripts, proteins, and metabolite levels. Among them, the differences at DNA and protein levels are generally small because they only exist in the inserted exogenous gene and its encoded protein. Therefore, most of the currently used methods and techniques for GEO analysis have been developed based on DNA and protein analysis (Figure 34.1) [10].

34.3.1 Detection Methods and Technologies Based on Protein Analysis

Detection methods and technologies of engineered exogenous proteins are established on the general immunology principle of antigen-antibody binding, which can be visualized and/or analyzed rather quickly by chemical or fluorescent color reactions [11]. The enzyme-linked immunosorbent assay (ELISA) and lateral flow devices (LFD) are two commonly used methods for exogenous protein detection in GEO food/feed samples [12].

In ELISA, antigens in the samples are first attached to the surface of a reaction well, and then the antibody specific to the target antigen is added to bind the attached antigen. The antibody is linked to an enzyme that will produce detectable chemical or fluorescent signals when the enzyme's substrate is present. Recently, several ELISA methods have been developed for analysis of exogenous target proteins in several GEOs. Kim *et al.* developed two ELISA assays targeted at acetyl transferase encoded by the *bar* gene and neomycin phosphotransferase encoded by the *nptII* gene, respectively, for the detection of transgenic *Capsicum Subicho* lines [13]. Tan *et al.* established a sandwich

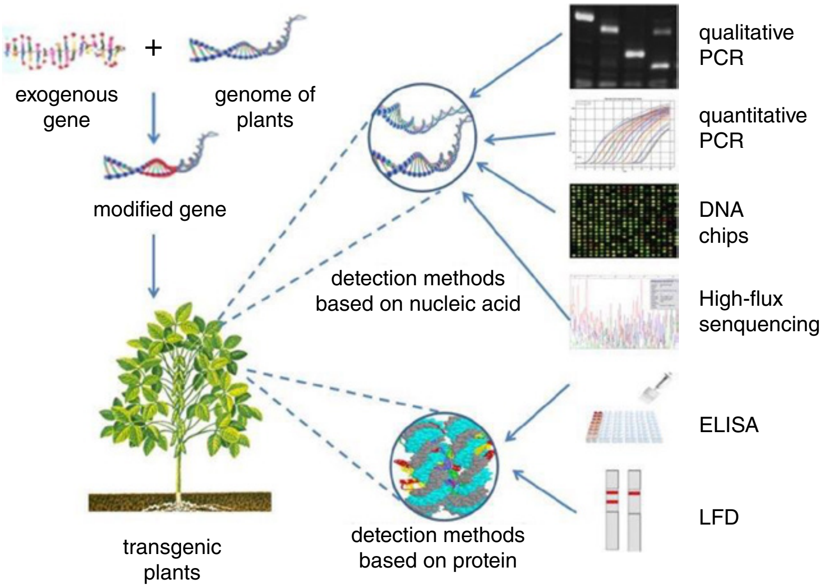


Figure 34.1 The main detection methods for GEOs. ELISA: Enzyme-linked immunosorbent assay, LFD: Lateral flow device [10].

ELISA detection of trypsin inhibitor (CpTI) protein in GEO cotton [14]. In Table 34.3, some commercial ELISA test kits targeting different transgenic exogenous proteins with limits of detection (LODs) as low as 0.1% are listed.

In strip tests using lateral flow devices (LFD), a thin strip made of nitrocellulose membrane is covered by a sample pad on one end and a wicking pad on the other. The sample pad is submersed in the extracted solution of homogenized test sample. The solution wicks up the nitrocellulose membrane strip and passes an area containing gold-labeled antibody which is specific to the target GEO protein. If that particular protein is present in the sample, it will specifically bind to the gold-labeled antibody; the resultant protein complex continues to move up the strip and reaches two additional areas on the strip, which are the test line and the control line. The test line contains a second antibody which is also specific to the target GEO protein. When the gold-labeled antibody-GEO protein complex reaches the test line, it forms an antibody-target-antibody sandwich with the immobilized second capture antibody. The result is the formation of a visible line on the strip, indicating that the target GEO protein is present in the sample [15]. In GEO analyses, LFDs are often used for field sample tests or quick screening in routine analysis. LFDs that can detect multiple GEO target proteins in a single strip have also been reported. Liu *et al.* developed a LFD strip that can be used for detection of human lactoferrin (HLF) protein in transgenic cattle and sheep [16]. Table 34.3 lists some of the commercialized LFDs used in GEO detection [17].

Table 34.3 Commercialized protein detection methods/kits of GEOs [17].

Exogenous target protein	Transgenic plants	Detection methods	
		ELISA	LFD
Cry 1A	Maize, cotton	Yes	No
Cry 1Ab	Cotton	Yes	Yes
Cry 1Ac	Cotton	Yes	Yes
Cry 1F	Maize, cotton	Yes	Yes
Cry 2A	Cotton, maize	Yes	Yes
Cry 2Ab	Maize, cotton	Yes	No
Cry 2Ae	Cotton	No	Yes
Cry 34	Maize	Yes	Yes
Cry 34Ab1	Maize	Yes	Yes
Cry 3B	Maize	Yes	No
Cry 3Bb	Maize	Yes	No
Cry 9C	Maize	Yes	Yes
Modified Cry 3A	Maize	Yes	Yes
CP4 EPSPS	Maize, cotton, rapeseed, clover, bean	Yes	Yes
PAT/*bar*	Rice, cotton	Yes	Yes
PAT	Maize, bean, rapeseed	Yes	Yes
Vip3A	Cotton, maize	Yes	Yes

34.3.2 PCR Technologies and Strategies for GEO Detection

Because of the higher stability of nucleic acids than proteins, most GEO detection methods have been developed by targeting exogenous DNAs [18]. Hundreds of PCR and/or real-time PCR assays of various GEO events have been published (Table 34.4). The overall procedures for all PCR-based GEO analyses are quite similar (illustrated in Figure 34.2), including three general steps:

1) *Detection of possible GEO content.* In this step, universal elements and marker genes for genetic engineering are often targeted for quick screening of GEO contents in feed/food samples. If the initial screening results are positive, the samples will be further tested in step 2.
2) *Characterization of the GEO event.* In this step, event-specific PCR assays are used to determine which GEO event the detected GEO content is from.
3) *Quantification of the GEO content.* After the GEO event is determined, event-specific quantitative real-time PCR assays are used to quantify the GEO content in the tested feed/food samples [3, 10].

34.3.3 New Nucleic Acid-Based Analytical Technologies for GEO Analysis

34.3.3.1 Multiplex Target Analysis Based on PCR

Hundreds of new GEO crop events have been released and approved for planting worldwide in the past two decades, which creates great demand for the development of accurate and rapid high-throughput detection methods, especially methods targeting multiple GEO events in a single detection. Several new multiplex PCR strategies have been developed for GEO analysis, such as conventional multiplex PCR, degenerate PCR, and emulsion PCR. Multiplex PCR refers to the use of polymerase chain reaction to amplify several different DNA sequences simultaneously. Multiplex-PCR consists of multiple primer sets within a single PCR reaction to produce amplicons of varying sizes that can be analyzed by agarose gel electrophoresis or capillary gel electrophoresis. Lu *et al.* developed a multiplex PCR assay for the detection of six transgenic elements, including the *CaMV35S* promoter, *NOS* promoter, *NOS* terminator, nptII gene, *cp4EPSPS* gene, and *pat* gene [19]. Degenerate PCR uses degenerate primers to amplify multiple DNA sequences that are related; these degenerate primers are mixtures of primers with similar sequences. Guo *et al.* established a multiplex degenerate PCR assay that can amplify eight exogenous genes using four degenerate primer pairs, and in theory this assay could be used for detection of more than 90 GEO events [20]. In emulsion PCR, individual DNA molecules along with primers can be embedded in aqueous droplets within an oil phase, and the individual DNA molecules can be amplified in more than 10^7 reactions to avoid interference among multiple primers and templates. Guo *et al.* also developed a novel high-throughput multiple DNA target analysis named Microdroplet PCR Implemented Capillary gel electrophoresis (MPIC); 24 transgenic DNA targets can be simultaneously detected using MPIC with anLOD of 39 copies of genomic DNA [21].

34.3.3.2 DNA Microarrays

A DNA microarray, also known as a DNA chip or biochip, is a collection of microscopic DNA spots fixed to a solid surface. A large number of genes can be simultaneously

Table 34.4 Reported/verified detection methods of GEOs [17].

	Qualitative PCR method			Quantitative PCR method		
Strategies	**Targets of detection**	**Detection Limits**	**Whether To Verify**	**Targets of detection**	**Detection limits**	**Whether to verify**
Screening	*CaMV35S promoter*, *FMV35S promoter*, NOS terminator	0.1%	Yes	*CaMV35S promoter*	0.05%	yes
	Ubiqutin promoter, RiceActin promoter, *Nos promoter*, *CaMV35S terminator*	0.1%	No	*FMV35S promoter*, *Nos terminator*, *Nos promoter*, *CaMV35S terminator*	0.01%	no
	Bla gene, gus gene, hpt gene, nptii gene	0.1%	Yes	*Bla gene, gus gene, hpt gene, nptii gene*	0.01%	no
Gene	*18SrRNA, aadA, bxn, CP, cry1Ab, cry1F, cry2Ab, cry9C, epsps, gox, RP, uidA, vip3A(a), phytase, cptI, Phytase*	0.1%		*Aad, acp1, bar, CP, cp4 epsps, cry1Ab/c, cry1Ac, cry2Ab, cry3A, FatA, gox, pat, RP*	0.01%	no
	bar, Barnase, cryIA(b), cry1Ac, cry3A, plrv rep, pat	0.1%	Yes	*cry1Ab, cry1A, 105, cry2Ab2*	0.05%	yes
Construct	MON531 cotton, MON1445 cotton, GK19 cotton, SGK321 cotton, TT51-1 rice, KMD rice, GA21 maize, MON810 maize, MON863 maize, NK603 maize, TC1507 maize, Huafan 1 tomato	0.1%	No	Huafan 1 tomato	0.01%	no
	Nema282F tomato, Bt11 maize, Event176 maize, T25 maize, GTS-40-3-2 bean, Bt63 rice, FP967 fiberflax	0.1%	Yes	*ctp2-cp4epsps*, MON810 maize, Bt11 maize, Event176 maize, GA21 maize, GTS-40-3-2 bean	0.05%	yes

(Continued)

Table 34.4 (Continued)

	Qualitative PCR method			Quantitative PCR method		
Strategies	**Targets of detection**	**Detection Limits**	**Whether To Verify**	**Targets of detection**	**Detection limits**	**Whether to verify**
Event	Rapeseed (Ms8, Rf3, GT73, Ms1, RF1, Rf2, Topas 19/2, T45, Oxy235)	0.1%	Yes	Rapeseed (Ms8, Rf3, GT73, Ms1, RF1, Rf2, Topas 19/2)	0.05%	yes
	Sugarbeet H7-1	0.1%	Yes	Sugarbeet H7-1	0.05%	yes
	Cotton (LLCotton25, MON1445, MON531, MON15985, MON88913, GHB119)	0.1%	Yes	Cotton (281-24-236, 3006-210-23, LLCotton25, MON1445, MON531, MON15985, MON88913, GHB119, T304-40)	0.05%	yes
	Bean (DP-356043-5, 305423, A5547-127, MON89788, GTS-40-3-2, A2704-12, MON87769, CV127)	0.1%	Yes	Bean (DP-356043-5, 305423, A5547-127, MON89788, GTS-40-3-2, A2704-12, MON87701, MON87705, MON87769, FG72, CV127)	0.05%	yes
	Maize (MON810, 3272, MON89034, LY038, MIR162, Bt176, MON88017, Bt11, GA21, MIR604, 59122, T25, TC1507, MON863, NK603, Bt10)	0.1%	Yes	Maize (98140, MON810, 3272, MON89034, LY038, MIR162, Bt176, MON88017, Bt11, GA21, MIR604, 59122, T25, TC1507, MON863, MON87460, NK603, Bt10, DAS-40278-9)	0.05%	yes
	Maize (MON810, 3272, MON89034, LY038, MIR162, Bt176, MON88017, Bt11, GA21, MIR604, 59122, T25, TC1507, MON863, NK603, Bt10)	0.1%	Yes	Maize (98140, MON810, 3272, MON89034, LY038, MIR162, Bt176, MON88017, Bt11, GA21, MIR604, 59122, T25, TC1507, MON863, MON87460, NK603, Bt10, DAS-40278-9)	0.05%	yes
	Rice (TT51-1, KMD, KF6, KF8, LLRICE601)	0.1%	Yes	Rice (Golden rice 2, TT51-1, LLRICE62, KMD, KF8, KF6)	0.05%	yes
				Potato EH92-527-1	0.01%	no
				Rapeseed T45 and Oxy235	0.01%	no

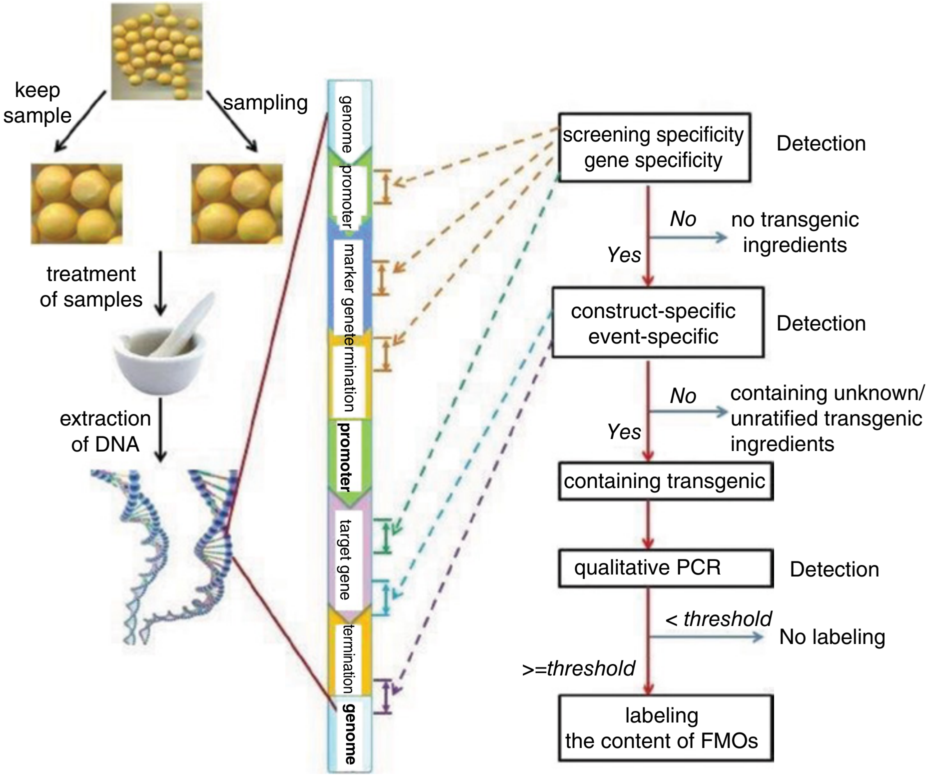


Figure 34.2 Strategies and procedures for GEO detection [10].

detected using one DNA chip, which makes it an attractive platform for high throughput analysis of multiple GEO targets. Shao *et al.* [22] developed a DNA chip-based assay called Multiplex Amplification on a Chip with Readout on an Oligo Microarray (MACRO) for GEO monitoring. Using MACRO, a total of 91 targets (18 universal elements, 20 exogenous genes, 45 GEO events, and 8 endogenous reference genes) can be detected, which covers 97.1% of all GEO events that had been commercialized by 2012. The LOD of MACRO is ≤10 copies for each target, and the high accuracy was confirmed by testing practical samples and double blind samples. Nesvold *et al.* [23] designed a DNA chip to detect unknown GEOs. The newly developed tiling array that contains high-density tile-type oligonucleotide probes may also be used for monitoring transgenic DNA at the whole genome level. One such tiling array has been reported to detect unknown or unauthorized GEOs employing GEO *Arabidopsis* as an example [24].

34.3.3.3 Next-Generation Sequencing (NGS)

NGS has greatly improved DNA sequencing technology and has overcome many weaknesses of first-generation sequencing methods, such as low throughput/scalability, slow speed, and low resolution. NGS allows massive parallel sequencing, which reduces cost and increases sequencing speed. Currently, there are several commercial NGS platforms, such as Massively Parallel Signature Sequencing (MPSS), 454 pyrosequencing, Illumina (Solexa) sequencing, SOLiD sequencing, DNA nanoball sequencing, and

Heliscope single molecule sequencing, and so on. Some of these new NGS technologies have been used for GEO analysis and shown good application prospects. Toestein *et al.* [25] established a computer algorithm to reveal an unknown GEO *Arabidopsis thaliana* using 454 pyrosequencing data, which opened the door for possible application of NGS in analysis of unknown GEOs. Yang *et al.* [26] developed the TranSeq tool with three modules to reveal the molecular characterization of GEOs. TranSeq has been used successfully to characterize the transgene insertion, flanking sequences, and copy numbers of two GEO rice events.

34.3.3.4 Loop-Mediated Isothermal Amplification (LAMP)

Isothermal amplification is a DNA amplification technology that amplifies target DNAs at constant temperature without the need for PCR cyclers. Several isothermal amplification methods have been developed and used for GEO analysis, such as RCA, SDA, RPA, LAMP, and NASBA. Among them, LAMP is the most widely used isothermal amplification method. In this technique, the target sequence is amplified at a constant temperature of 60–65°C using two or three sets of primers and a polymerase with high replication and strand displacement activities. Typically, four different primers are used to identify six distinct regions in the target gene, which makes LAMP amplification highly specific. The addition of an additional pair of loop primers can further accelerate the LAMP reaction [27]. Lee *et al.* [28] detected the CaMV35S promoter and NOS terminator in GEO soybean and canola using LAMP with LODs of 0.01%; Guan *et al.* [29] developed a visual LAMP method employing fluorescent dye to detect the GEO soybean events MON89788 and GTS 40-3-2; Chen *et al.* [30] reported seven visual LAMP assays for GEO maize events; Kiddle *et al.* [31] developed an on-the-spot detection device by combining LAMP technology with the fluorescent reporter gene BART, which can detect transgenic ingredients as low as 0.1%; Zhang *et al.* [32] also established an on-the-spot test of field samples using visual LAMP combined with a rapid DNA extraction device; Wang *et al.* [33] have developed a series of LAMP assays for screening of GEO content by targeting commonly used transgenic elements and marker genes.

34.3.3.5 Digital PCR

Digital PCR (dPCR) is a refinement of conventional PCR and can be used for direct quantification and clonal amplification of nucleic acids. In digital PCR, a nucleic acid sample is diluted into a large number of partitions, and the amplification reaction is carried out in each partition individually. The partitioning of the sample allows the number of different molecules to be estimated by assuming that the molecule population follows the Poisson distribution [34]. At present, there are three commercial digital PCR platforms, which are the champer dPCR based on an integrated fluidic circuit (IFC) chip, droplet digital PCR based on emulsion droplet, and 3D dPCR based on a pro-hydrophobic chip (Figure 34.3). Digital PCR can be used in GEO detection, and is especially useful in characterizing the values of certified reference materials (CRMs) [35]. Corbisier *et al.* [36] carried out the absolute quantification of endogenous and exogenous gene fragments of Mon810 maize CRMs using dPCR; Morisset *et al.* [37] developed several dPCR methods for GEO detection and compared these methods with quantitative real-time PCR, concluding that dPCR is more accurate and reliable; Burns *et al.* [38] studies whether dPCR is suitable for characterizing the values of CRMs and analysis of GEO samples with very low GEO contents.

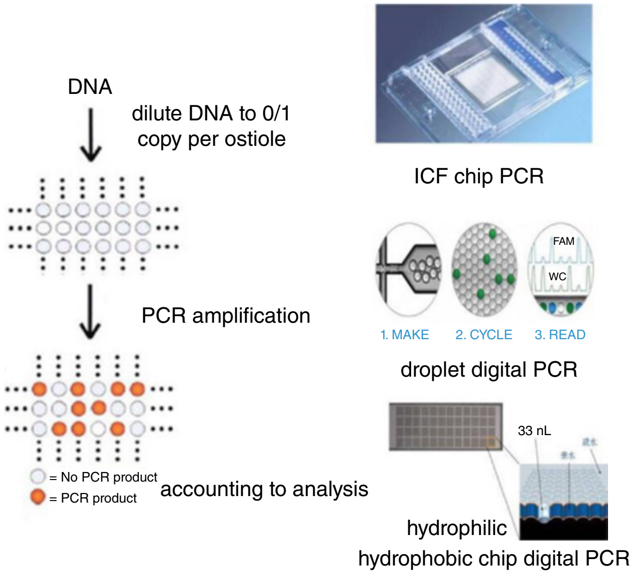


Figure 34.3 Principles of digital PCR and three different digital PCR platforms.

34.3.4 Biosensors for GEO Analysis

A biosensor is an analytical device that combines a biological component with a physicochemical detector. The sensitive biological element interacts with the target analyte, and the physicochemical detector element transforms the signal resulting from the interaction into measurable and quantifiable data, which can then be recorded and displayed by the associated electronic signal processors [39]. Biosensors that employ nucleic acid interactions (genosensors) are established based on the principle of complementary nucleobase pairing. If a target nucleic acid sequence is available, complementary sequences can be synthesized, labeled, and immobilized into a biosensor. The pairing of labelled probe and target sequences generate optical signals that can be picked up by the detector [39]. Genosensors targeting the CaMV35s promoter and NOS terminator, have been developed for screening of GEO content [40]. Currently there are three major types of biosensor used in GEO analysis: electrochemical biosensor, optical biosensor, and piezoeletric quartz crystal biosensor. Electrochemical biosensors are based on enzymatic reactions that either produce or consume electrons. There are three electrodes in an electrochemical biosensor: a reference electrode, a working electrode, and a counter electrode. The enzymatic reactions of the target analyte take place on the active electrode surface, and the reaction will either cause electron transfer across the double layer or contribute to the double layer potential [41]. Optical biosensors can detect the interaction between microorganisms and target analytes, and correlate optical signals to the concentrations of target compounds. Unlike electrochemical biosensors, optical biosensors measure photons generated in the process rather than electrons [42]. Surface plasmon resonance (SPR) is a powerful optical technique that can detect various biomolecular interactions happening at the interface of a thin gold-coated prism which is in contact with the flow of analyte solution. Feriotto *et al.* developed an SPR-based assay named biospecific interaction analysis (BIA) for the detection of soybean lectin and Roundup Ready transgene sequences. Different formats using oligonucleotide- or PCR-generated probes against single-stranded target PCR products were both demonstrated to be successful [43]. Piezoelectric quartz crystal biosensor, such as quartz crystal membrane (QCM), is a mass-sensitive piezoelectric device based on oscillatory quartz crystal and capable of detecting mass changes in nanograms. The underlying principle is that when a monolayer or thin film is formed on the quartz wafer sandwiched between two electrodes, an oscillating electric field produces mechanical resonance [44]. QCM can monitor interactions that cause increases in mass and decreases in resonance frequency in real time. In GEO detection, piezoelectric biosensors can be applied because hybridization of a probe and its target DNA sequence will cause an increase in mass [45]. One QCM sensor has been developed for the detection of CaMV35S promoter and NOS terminator sequences in GEO plants. Hybridization between immobilized single-stranded DNA (ssDNA) probes on the gold surface and target sequences in solution could be successfully monitored, demonstrating that QCM could be a useful tool for GEO screening of food samples [45].

34.3.5 Spectrum Detection Method

Chromatography technology is widely used in modern food safety analysis. It can separate complex food samples by differential distribution of different components between the stationary and mobile phases in a chromatography column. The concentrations of fatty acids and triglycerides often differ between GEO and non-GEO rapeseeds, and a chromatography assay of GEO rapeseed has been developed, since fatty acids and triglycerides can be efficiently separated and detected by chromatography [46]. For example, an HPLC-APIC-MS assay has been developed to detect differences in triglycerides between transgenic and non-transgenic rapeseed for monitoring of GEO rapeseed. However, the reported chromatography assay of GEOs is currently limited to transgenic plants with altered fatty acids, and only in qualitative analysis [47].

Near infrared (NIR) fluorescence can reveal chemical composition in a sample based on its physical properties. By hitting a sample with near infrared light, chemical bonds in the molecules vibrate and re-release light energy at a wavelength characteristic to a specific molecule or chemical bond. The key step in NIR analysis is to build an appropriate rectification model that can correlate physical and chemical properties of a molecule to its near infrared spectroscopy [48]. Near infrared (NIR) spectroscopy and multivariate classification has been applied to soybean oil analysis. After mean centering and multiplicative scatter correction, support vectors machine-discriminant analysis (SVM-DA) and partial least squares-discriminant analysis (PLS-DA) were applied on NIR spectroscopy to provide a rapid, non-destructive and reliable method to distinguish non-transgenic and transgenic soybean oils [49]. One caveat of NIR is that it can only be used when the differences between GEO and non-GEO samples are big enough. It is also difficult to quantify mixed samples using NIR, and there is a long way to go to establish a standard procedure for utilizing NIR in GEO detection.

34.4 Standardization of GEO Detection Methods

Many countries and regions have established a series of GEO detection methods and systems to ensure the implementation of GEO labeling regulations, and how to standardize the various detection methods has become an important issue. The International Standard Organization (ISO) has set up a professional committee to develop standards for GEO detection, and a serial of standards have been published (ISO24276, ISO21569, ISO21570, ISO21571, ISO21572, and ISO21098), covering subjects such as General Definition and Principle, DNA extraction, Qualitative PCR analysis, Quantitative real-time PCR analysis, and New methods update, and so on [50]. In the EU, a standard system for GEO feeds/foods detection has also been established, including standards on information collection, development of detection methods, methods validation, proficiency testing, and development of certified reference materials, and so on. To date, more than 51 event-specific detection methods have been developed and validated for GEO maize, GEO soybean, GEO cotton, GEO canola, GEO rice, GEO potato, and GEO sugar beet, and so on [51]. In China, standards for GEO detection methods based on conventional PCR and quantitative real-time PCR have also been published. A total of 116 national standard methods have been published for screening, identification, and quantification of GEO contents.

34.5 Database for GEO Analysis

Information about the inserted exogenous genes and their flanking sequences of various GEO events is the key to establish effective detection methods, and primers and probes for PCR, real-time PCR, and LAMP assays are designed based on the sequence information. Databases providing information on transgenic sequences and their detection methods will greatly benefit people working on GEO analysis. Currently, several such databases focusing on GEOs have been developed, such as GMDD (GMO Detection Database, http://gmdd.shgmo.org), GM Crop Database (http://cera-gmc.org), GMO Methods (http://gmo-crl.jrc.ec.europa.eu/gmomethods), GMO Compass (http://www.gmo-compass.org), and Biosafety Cleaning-house (BCH; http://bch.cbd.int) and so on the [10]. GMDD is a professional database focused on collecting the molecular characterization of commercialized GEO events, detection methods, and CRMs. This database provides more than 500 published detection methods for more than 220 GEO events, and more than 800 sequences of exogenous genes with corresponding integration sites and transformation vectors, and so on. In GM Crop Database, basic information (exogenous gene, transform vector, transformation method, etc.) and safety assessment reports (molecular characterization, environmental risk assessment, and food safety risk assessment, etc.) of commercialized GEO plants worldwide are collected. GEO Methods database mainly provides qualitative PCR and quantitative PCR methods validated by international collaborative ring trials. GEO Compass focuses on information on GEO plants and products approved in the EU. BCH was set up using the Cartagena Protocol on Biosafety to facilitate the exchange of information on living modified organisms (LMOs) and assist the parties to better comply with their obligations under the Protocol. Scientific, technical, environmental, legal, and capacity-building information is provided in BCH. The development and operation of these databases have effectively improved risk assessment and detection method standardization globally.

34.6 Prospects

Following the fast development and application of transgenic technologies in modern agricultural production, more and more GEO products have appeared in our daily life.

To implement safety regulations and GEO labelling policies, the development and standardization of various GEO detection methods are becoming a major issue in food science.

In China, the research and development of GEO detection methods have been strengthened since GEO cotton was approved for planting in 1996. In particular, the Chinese government issued regulations and labeling for agricultural GEOs and their derivates in 2001, which ensured the healthy development of GEO research and commercialization in China, and great progress in the development and standardization of GEO detection methods. Although effective GEO inspection and monitoring systems have been established in China, there are still gaps in these areas between China and other countries with advanced GEO technologies, such as the US, Canada, and the EU. For example, many current GEO detection methods are still only based on conventional qualitative PCR methods. As more domestically developed GEOs are likely be approved for commercialization in China in the future, the labeling threshold might be changed from zero currently to a specific value, and if so, more real-time PCR, digital PCR, or other quantitative detection methods need to be developed, validated, and applied in routine GEO analysis.

In the past two decades, the major engineered traits of GEO plants have been insect resistance and herbicide tolerance, and major inserted exogenous genes include Bt family genes, EPSPS, Bar/Pat and so on. Protein-based detection methods have been focused on targeting proteins encoded by these exogenous genes, and corresponding monoclonal antibodies have been produced and used to develop GEO assay ELISA kits and LFDs. Today many of these protein-based GEO detection methods or kits are mainly imported from foreign countries, and it’s also a great challenge to create antibodies for many new proteins that are encoded by new exogenous genes being engineered, so the development of protein-based GEO analysis methods and products needs to be strengthened in China.

LLP has become a commonly encountered situation in imported GEO soybean and maize samples. Several researches and discussions related to LLP have been conducted in CAC, the US, and the EU, and effective regulations or guidelines regarding LLP have been issued to avoid potential disputes and economic losses in international trade. It is particularly difficult to avoid LLP issues in China because of its zero threshold labeling regulations. More domestic GEO plants are likely to be approved for planting in China, but might not be approved in other countries, and this could create LLP issues in the export of agricultural products. Since monitoring of LLP is depended on the selected detection method and its sensitivity, effective inspection and monitoring methods for LLP of unauthorized GEOs or unknown GEOs should be developed and established accordingly.

In addition to commonly used PCR, ELISA, and LFD methods in GEO analysis, many new techniques are being developed and used in GEO analysis, such as digital PCR, NGS, and biosensors and so on. As more and more GEOs are being developed, improving high throughput GEO detection methods is becoming a trend in GEO analysis, for which NGS, emulsion droplet PCR, and microarrays are suitable technologies. All the methods and technologies that have been applied and are being developed will greatly improve the global efforts in effective GEO regulation and labeling, both domestically and internationally.

References

1 James, C (2014) *Global Status of Commercialized Biotech/GM Crops: 2014.* ISAAA Brief No. 49. ISAAA: Ithaca, NY

2 Klümper W, Qaim M (2014) A meta-analysis of the impacts of genetically modified crops. *PLoS One.* 9(11): e111629.

3 Zhang D, Guo J (2011). The development and standardization of testing methods for genetically modified organisms and their derived products. *Journal of Integrative Plant Biology*, 53(7): 539–551.

4 Li Y, Song G, Shen P, Zhao X, Zhou Y (2013) The "value" expression pattern and technical procedure for genetically modified organism detection reference materials. *Scientia Agricultura Sinica*, 46(4): 800–809 [in Chinese].

5 Gruère GP, Rao SR (2007). A review of international labeling policies of genetically modified food to evaluate India's proposed rule. *Journal of Agro-biotechnology Management and Economics*, 10(1): 51–64.

6 Li N, Fu Z, Liu P, Li H, Lian Q (2010). Comparing of administration policy of main countries on GMOs. *Management of Agricultural Science and Technology*, 29(1): 1–6.

7 CAC Annex 3 on Food Safety Assessment in Situations of Low-level Presence of Recombinant-DNA Plant Material in Food. http://www.fao.org/fileadmin/user_upload/agns/topics/LLP/Presentations/04_Codex_Final.pdf (accessed November 2016).

8 Xu L, Li N, Tian Z (2012). Analysis on the Low Level Presence of Genetically Modified Product. *Journal of China Agricultural University.* 29(2): 125–132 [in Chinese].

9 Commission Regulation (EU) No 619/2011 Laying down the methods of sampling and analysis for the official control of feed as regards presence of genetically modified material for which an authorisation procedure is pending or the authorisation of which has expired. http://www.genetic-id.com/Pages_link/Regulation-EU-619-2011.pdf (accessed November 2016).

10 Wang R, Jiang Y, Wei J, Zhang D, Yang L (2013) The labeling and detection of genetically modified organisms and their derivates. *Plant Physiology Journal*,7: 645–654 [in Chinese].

11 Holst-Jensen A (2009). Testing for genetically modified organisms (GMOs): Past, present and future perspectives. *Biotechnology Advance*, 27(6): 1071–1082.

12 Michelini E, Simoni P, Cevenini L (2008). New trends in bioanalytical tools for the detection of genetically modified organisms: an update. *Analytical and Bioanalytical Chemistry*, 392(3): 355–367

13 Kim HJ, Lee SM, Kim JW, Ryu TH, Suh SC, Cho HS (2010). Expression of PAT and NPT II Proteins during the developmental stages of a genetically modified pepper developed in Korea. *Journal of Agricultural and Food Chemistry*, 58: 10906–10910.

14 Tan G, Nan T, Gao W, Li Q, Cui J, Wang B (2013) Development of monoclonal antibody-based sensitive sandwich ELISA for the detection of antinutritional factor cowpea trypsin inhibitor. *Food Analytical Methods.* 6: 614–620.

15 Lipp, Anklam M, Stave E, JW (2000). Validation of an immunoassay for the detection and quantification of Roundup Ready soybeans in food and food fractions by the use of reference material. *Journal of AOAC International*, 83: 919–927

16 Liu C, Zhai S, Zhang Q, Liu B (2013). Immunochromatrography detection of human lactoferrin protein in milk from transgenic cattle. *Journal of AOAC International*, 969(1): 116–120

17 Yang, L, Zhang, D., Guo, J. (2016). New techniques for genetically modified organism analysis. Chapter 32 in *Food Safety in China: Past, Present and Future.* (ed. Jen, J and Chen, J). China Science and Technology Press, Beijing, China pp. 423–440. [in Chinese].

18 Zhang J, Liu Y, Zhang H, Yang L (2011). A research advance in the technology of detecting GMOs. *Acta Agriulturase Shanghai*, 27(1): 117–120 [in Chinese].

19 Lu, Lin CH, Pan TM (2010). Establishment of a system based on universal multiplex-PCR for screening genetically modified crops. *Analytical and Bioanalytical Chemistry*, 396: 2055–2064.

20 Guo J, Chen L, Liu X, Gao Y, Zhang D, Yang LT (2012) A multiplex degenerate PCR analytical approach targeting to eight genes for screening GMOs. *Food Chemistry*, 132(3), 1566–1573.

21 Guo J, Yang L, Chen L, Morisset D, Li X, Pan L, Zhang D (2011). MPIC: a high-throughput analytical method for multiple DNA targets. *Analytical Chemistry*, 83 (5): 1579–1586.

22 Shao N, S Jiang, M Zhang, J Wang, S Guo, Y Li, H Jiang, C Liu, D Zhang, L Yang, S Tao (2014). MACRO: A combined microchip-PCR and microarray system for high-throughput monitoring of genetically modified organisms. *Analytical Chemistry*, 86 (2): 1269–1276.

23 Nesvold H, Kristoffersen AB, Holst-Jensen A, Berdal KG (2005). Design of a DNA chip for detection of unknown genetically modified organisms (GMOs). *Bioinformatics*, 21(9), 1917–1926.

24 Mockler TC, Ecker JR (2005). Applications of DNA tiling arrays for whole-genome analysis. *Genomics*, 85:1–15.

25 Tengs T, Zhang H, Holst-Jensen A, Bohlin J, Butenko MA, Kristoffersen AB, Sorteberg HO, Berdal KG (2009). Characterization of unknown genetic modifications using high throughput sequencing and computational subtraction. *BMC Biotechnology*, 9: 87–93.

26 Yang L, Wang CM, Holst-Jensen A, Morisset D, Lin YJ, Zhang DB (2013) Characterization of GM events by insert knowledge adapted re-sequencing approaches. *Scientific Reports*, 3: 2839.

27 Notomi T, Okayama H, Masubuchi H, Yonekawa T, Watanabe K, Amino N, Hase T (2000). Loop-mediated isothermal amplification of DNA. *Nucleic Acids Research*, 28: 63–69.

28 Lee D, Mura ML, Allnutt TR, Powell W (2009). Detection of genetically modified organisms (GMOs) using isothermal amplification of target DNA sequences. *BMC Biotechnology*, 9: 7–13.

29 Guan X, Guo J, Shen Ping, Yang L, Zhang D (2010) Visual and rapid detection of two genetically modified soybean events using loop-mediated isothermal amplification method, *Food Analysis Methods*, 3(4): 313–320.

30 Chen L, Guo J, Wang Q, Kai G, Yang L (2011). Development of the visual loop-mediated isothermal amplification assays for seven genetically modified maize events and their application in practical samples analysis. *Journal of Agricultural and Food Chemistry*, 59(11): 5914–5918.

31 Kiddle G, Hardinge P, Buttigieg N, *et al.* (2012). GMO detection using a bioluminescent real time reporter (BART) of loop mediated isothermal amplification (LAMP) suitable for field use. *BMC Biotechnology*, 12: 15–27

32 Zhang M, Liu Y, Chen L, Quan S, Jiang S, Zhang D, Yang L (2013). One simple DNA extraction device and its combination with modified visual loop-mediated isothermal amplification for rapid on-field detection of genetically modified organisms. *Analytical Chemistry*, 85(1): 75–82.

33 Wang C, Li R, Quan S, Shen P, Zhang D, Shi J, Yang L (2015) GMO detection in food and feed through screening by visual loop-mediated isothermal amplification assays. *Analytical and Bioanalytical Chemistry*, 407(16): 4829–4834.

34 Pohl G, Shih LM (2004). Principle and applications of digital PCR. *Journal of Molecular Diagnostics*, 4(1): 41–47

35 Brod FC, van Dijk JP, Voorhuijzen MM, Dinon AZ, Guimarães LH, Scholtens IM, Arisi AC, Kok EJ (2014) A high-throughput method for GMO multi-detection using a microfluidic dynamic array. *Analytical and Bioanalytical Chemistry*, 406(5): 1397–1410.

36 Corbisier P, Bhat S, Partis L, Xie VR, Emslie KR. (2010) Absolute quantification of genetically modified MON810 maize (*Zea mays* L.) by digital polymerase chain reaction. *Analytical and Bioanalytical Chemistry*, 396(6): 2143–2150.

37 Morisset D, Štebih D, Milavec M, Gruden K, Žel J (2013) Quantitative analysis of food and feed samples with droplet digital PCR. *PLoS One*, 8(5): e62583.

38 Burns MJ, Burrell AM, Foy CA (2010). The applicability of digital PCR for the assessment of detection limits in GMO analysis. *European Food Research Technology*, 231: 353–362.

39 Michelini E, Simoni P, Cevenini L, Mezzanotte L, Roda A (2008) New trends in bioanalytical tools for the detection of genetically modified organisms: an update. *Analytical and Bioanalytical Chemistry*, 392(3): 355–367.

40 Sun W, Zhong J, Qin P, Jiao K. (2008) Electrochemical biosensor for the detection of cauliflower mosaic virus 35 S gene sequences using lead sulfide nanoparticles as oligonucleotide labels. *Analytical Biochemistry*, 377(2): 115–119.

41 Huang L, Zheng L, Chen Y, Xue F, Cheng L, Adeloju SB, Chen W (2015) A novel GMO biosensor for rapid ultrasensitive and simultaneous detection of multiple DNA components in GMO products. *Biosensors and Bioelectronics*, 66: 431–437.

42 Zhao Z, Chen Y, Xu W, Ma M (2013). Surface plasmon resonance detection of transgenic Cry1Ac cotton (*Gossypium* spp.). *Journal of Agricultural Food Chemistry*, 61: 2964–2969.

43 Feriotto G, Gardenghi S, Bianchi N, Gambari R (2003) Quantitation of Bt-176 maize genomic sequences by surface plasmon resonance-based biospecific interaction analysis of multiplex polymerase chain reaction (PCR). *Journal of Agricultural Food Chemistry*, 51(16): 4640–4646.

44 Ogi H (2013) Wireless-electrodeless quartz-crystal-microbalance biosensors for studying interactions among biomolecules: a review. *Proceedings of the Japanese Academy Series B Physical and Biological Sciences*, 89(9):401–417.

45 Mannelli I, Minunni M, Tombelli S, Mascini M. (2003) Quartz crystal microbalance (QCM) affinity biosensor for genetically modified organisms (GMOs) detection. *Biosensors and Bioelectronics*, 18(2–3): 129–140.

46 William C. Byrdwell, William E. Neff (1996) Analysis of genetically modified canola varieties by atmospheric pressure chemical ionization mass spectrometric and flame ionization detection. *Journal of Liquid Chromatography and Related Technologies.* 19(14): 2203–2225.

47 López MC, Garcia-Cañas V, Alegre ML. (2009) Reversed-phase high-performance liquid chromatography-electrospray mass spectrometry profiling of transgenic and non-transgenic maize for cultivar characterization. *Journal of Chromatography A*, 1216(43): 7222–7228.

48 Ozaki Y. (2012) Near-infrared spectroscopy--its versatility in analytical chemistry. *Analytical Science*, 28(6): 545–563.

49 Luna AS, da Silva AP, Pinho JS, Ferré J, Boqué R. (2012) Rapid characterization of transgenic and non-transgenic soybean oils by chemometric methods using NIR spectroscopy. *Spectrochimica Acta Part A, Molecular and Biomolecular Spectroscopy*, 100: 115–119.

50 Liu X, Song G, Shen P, Li J (2007). A review of testing technology for transgenic plants and standardization abroad. *Management of Agricultural Science and Technology*, 26(4): 3–7 [in Chinese].

51 European Commission. EU Database of Reference Methods for GMO Analysis http://gmo-crl.jrc.ec.europa.eu/gmomethods/ (accessed November 2016).

35

Safety of Food Contact Materials and Articles in China

Rongfang Chen[1] *and Yanyun Zhao*[2]

[1] *Shanghai Food and Drug Administration, China*
[2] *Department of Food Science and Technology, Oregon State University, USA*

35.1 Introduction

Packaging plays a significant role in the food system, with multiple functions including containing the food, protecting against biological, chemical, and physical damage to preserve food, and providing information essential to consumers and marketers [1]. Packaging is also a critical component of the overall food safety system, and plays a vital role in ensuring that the final product is safe and secure for consumption.

While various packaging technologies and materials have been developed for enhancing food quality and extending shelf-life, packaging can also be a vehicle for chemical, biological, and physical contaminants that lead to food safety risk. For example, due to the direct contact of packaging materials with food, toxic chemicals in food packaging materials, such as bisphenol A (BPA) may migrate into foods, and upon reaching certain levels, will result in a food safety risk and impact human health. Also, failure in packaging integrity and damage in packaging closure can cause recontamination of foods by microorganisms and chemicals, making the food unsafe to consume. In addition, new packaging technologies and materials, such as active and intelligent packaging, edible coatings/films, biodegradable packaging, and nanomaterial packaging may introduce new food safety challenges, while they have the potential to improve food quality, prolong self-life, and reduce the environmental impact. Therefore, regulations and standards on the use of current food packaging materials and technologies should be clearly established, and risk assessments of any new materials and emerging technologies should be implemented to prevent and control any potential food safety hazards. By focusing on food contact materials and articles, this chapter discusses the regulations and standards of food packaging in China, potential food safety hazards in existing food packaging systems, and also those related to emerging packaging technologies and materials, and challenges and strategies for ensuring the safety of food packaging.

Food Safety in China: Science, Technology, Management and Regulation, First Edition.
Edited by Joseph J. Jen and Junshi Chen.

35.2 Legislation on Food Contact Materials in China

35.2.1 Historical Evolution

Health supervision of food containers and packaging materials in China can be traced back to the 1960s. In 1964, the former Ministry of Health for China issued a notice to ban the production and use of food containers made of phenolic plastics due to food poisoning events from the use of lunch boxes made of this material. In 1965, the State Council approved and endorsed the "Provisional Regulations for Food Hygiene Management," jointly formulated by five ministries and bureaus (State Council (65) GUO-WEN-BAN-ZI No. 304), which takes food packaging materials into official management. The regulations stipulated that raw materials containing poisonous substances could not be used to manufacture food utensils, tableware, and packaging materials; paper and other materials that were intended to contact ready-to-eat foods, and food transport containers and tools should meet the hygienic requirements; new food packaging materials should be approved by the local health authorities before they could be put into use; and health administrations should be responsible for formulating the hygienic standards for food packaging materials [2]. In 1979, the State Council made a revision to the above regulations and officially issued the Regulations of the People's Republic of China for Food Hygiene Management. In 1974, the State Council approved and moved forward the Report on the Prevention of Food Contamination Problems submitted by the State Planning Commission (1974 Document No. 82), in which food containers and packaging materials were listed as one of the causes of food contamination. In the Food Hygiene Law of the People's Republic of China (For Trial Implementation), first issued on 19 November 1982, the hygiene management of food containers and packaging materials was upgraded to the legal management level, specifying that food containers, packaging materials, and utensils for food usage must meet the requirements of the hygiene standard and management; raw materials that are used to manufacture food containers, packaging materials, and utensils should comply with the hygienic requirements and the products should be easy to clean and sterilize; the health administrative departments of the State Council should be responsible for stimulating the related national hygiene standards, hygiene management measures, and testing protocols. After trial implementation of this Food Hygiene Law, the health departments worked out a series of hygiene standards and management measures on food containers and packaging materials applicable from 1984. After further revisions, the Food Hygiene Law of the People's Republic of China was officially put into effect on 30 October 1995. On 1 June 2009, the Food Safety Law of the People's Republic of China (revised in 2015) was enforced and replaced the former Food Hygiene Law, and has become the basic regulation for safety management of food contact materials. After a developmental course of more than 50 years, China has gradually established a relatively sound legal system for food contact materials. Since 1980, China has set up a national hygiene standard system involving seven categories and 59 items of food containers and packaging materials, including 20 resins and finished articles, eight coatings of food containers and equipment, and 31 metals, rubbers, paper, porcelain, casings, and additives for food container and packaging material use, and relevant testing methods. Based on the former Food Hygiene Law, the former Ministry of Health also laid out another 10 administrative rules, including the Rule for Hygiene Management of Inner

Coatings for Food Containers (Ministry of Health on 9 December 1986), the Rule for Hygiene Management of Plastic Products and Raw Materials for Food Use, and the Rule for Hygiene Management of Rubbers for Food Use (former Ministry of Health 1990 Order No. 8), but all these methods have been successively abolished after implementation of the Food Safety Law of the People's Republic of China according to Notice No. 67 of the Ministry of Health in 2009 and Notice No. 78 of the Ministry of Health in 2010 because of jurisdictional adjustments.

35.2.2 Current Regulation Systems

35.2.2.1 Basis of Laws and Regulations

The Food Safety Law of the People's Republic of China requires that food manufacturers and traders should undertake production and business activities in accordance with the laws, regulations, and food safety standards, assuring that foods should be nonpoisonous, harmless, and consistent with the necessary nutritional requirements, and do not cause any acute, sub-acute, sub-chronic, or chronic potential hazards to human health. Packaging materials, containers, and detergents for food use, and tools and equipment for food production and trading should be regarded as food-related products and managed accordingly; production, trading, and use of food-related products, and supervision and management of these food-related products should all follow the relevant requirements specified in the Food Safety Law of the People's Republic of China (see Article 2). Production of high-risk food-related products such as packaging materials intended to contact with foods directly should follow the national regulations for manufacturing licensing management of industrial products, and the related quality control authorities should have enhance their supervision and management of production activities of food-related products (see Article 41). Newly developed food-related products should be included in licensing management and cannot be used unless they have been assessed, examined, and approved by the health administrative departments of the State Council (see Article 37).

The Food Safety Law of the People's Republic of China only lists some food-related materials and products in the form of enumeration, without clearly defining whether or not adhesives, inks, and lubricating oils are within its management coverage, knowing that the components of these contact materials may migrate to foods, causing food safety problems. An example of such a food safety event is the 2-isopropylthioxanthone (ITX) contamination of infant formula manufactured by an internationally well-known food enterprise in 2005, which was caused by UV-cured printing ink [3, 4]. Food-related adhesives and inks are included in the management of food-contact materials and indirect food additives in European countries and the United States, respectively.

35.2.2.2 Mandatory Technical Standards

Food-related products should not only meet the relevant requirements of the Food Safety Law, but also comply with the relevant requirements of the mandatory technical standards (usually with titles starting with GB (which stands for national standard in Chinese) plus the standard number) and relevant notifications. Only resins or polymers that are listed in the currently valid standards and relevant notifications can be used. According to their scope of application, the mandatory food hygiene standards currently available can be classified into four categories: (i) hygiene standards for resins used for food containers and packaging materials (such as GB 9691 Hygiene Standard for Polyethylene Resin) and notifications from the National Health and Family Planning Commission (NHFPC) (including Notices No. 23 in 2011, No. 14 in 2013 and No. 14 in 2014); (ii) hygiene standards for finished products used for food containers and packaging materials (such as GB 9687 Hygiene Standard for Polyethylene Products); (iii) hygiene standards for additives used for food containers and packaging materials (such as GB 9685-2008 Hygiene Standard for the Uses of Additives in Food Containers and Packaging Materials, and relevant notifications, including Notices No. 5 in 2012, No. 11 in 2012, No. 1 in 2013 and No. 14 in 2013); and (iv) other national mandatory standards (such as GB 17762 Standard for Heat-Resistant Glass Vessels, and GB 15179 Standard For Lubricants of Food Machinery).

The current standards for food-contact resins and finished products cover most types of materials, including food containers and packaging made from plastic, rubber, ceramic, porcelain, stainless steel, aluminum, paper, detergents, disinfectants, lubricant, bamboo products, and laminated products. These standards specify the limits of related potential hazard substances including maximum use dosage (QM) in finished materials or articles, or the specific migration limits (SMLs), evaporate residues (or the overall migration limits, OML), the limits of potassium permanganate consumption, heavy metals (calculated according to lead (Pb)), and decolorization testing. As for the 109 resins approved in the relevant notifications, only the specific migration limits or residue limits, and conditions of use are defined without setting overall migration limits.

The current Hygiene Standard for the Uses of Additives in Food Containers and Packaging Materials (GB 9685-2008), which defines the use of additives for food-contact materials was first publicized in 1988. After three revisions in 1994, 2003, 2008, and 2016, the number of substances covered has increased from 56 to 1294. Including new additives issued in the related notifications, there are altogether about 1500 additives that are permitted for use in food-related products at present. The scope of standards application has also expanded from "auxiliary agents used in plastics, rubber, coating, paper, adhesives and inks for manufacturing food containers and packaging materials, food machinery, utensils and tools" to "substances that can improve or assist to improve the quality and properties, and processing aids to promote the production process but intended not to improve the quality and characteristics of the final articles, and some monomers and other starting materials for polymers used during the production processing of food containers and packaging materials." This standard also provides the principle of using additives for the production of food containers and packaging materials, the scope of application, the maximum dosage, and the SML or maximum residue in finished products for permitted additives (Table 35.1) [5], which is called the positive list of additives used for food-contact materials and articles in China.

35.2.2.3 Regulations for New Food-Related Products

Article 37 of the Food Safety Law specifies that the health administrative departments of the State Council are the competent authorities responsible for new food-related product applications, and that manufacturers or users of new food-related products should submit relevant safety assessment dossiers to the health administrative departments of the State Council and apply for approval before they put these products into the market. As for new types of food-related products issued publicly in the notices,

Table 35.1 Some requirements on authorized additives used in food contact materials.

Substance name	CAS No.	Scope of use	Maximum dosage (%)	SML or QM (mg/kg)	Remarks
Di-(2-ethylhexyl) phthalate (DEHP)	117-81-7	Plastic, coatings, rubber, adhesive	–	1.5 (SML)	Used as nonfatty food contact materials (FCM) only; prohibited for the use of infant FCM
Dimethylphthalate (DMP)	131-11-3	Plastic, adhesive	PP, PE, PS: 3.0	–	Used as nonfatty food contact materials (FCM) only; prohibited for the use of infant FCM
Diallylphthalate (DAP)	13117-9	Plastic, adhesive, paper, paperboard	–	ND (SML, DL = 0.01mg/kg)	Used as nonfatty food contact materials (FCM) only; prohibited for the use of infant FCM
Diisobutylphthalate (DIBP)	84-69-5	PVC, coatings, rubber, adhesive	PVC: 10.0	–	Used as nonfatty food contact materials (FCM) only; prohibited for the use of infant FCM
Diisononylphthalate (DINP)	28553-12-0	Plastic	–	9.0 (SML)	Used as nonfatty food contact materials (FCM) only; prohibited for the use of infant FCM
Diisooctylphthalate (DIOP)	27554-26-3	Plastic, rubber,	40.0	–	Used as nonfatty food contact materials (FCM) only; prohibited for the use of infant FCM
Dibutylphthalate (DBP))	84-74-2	Plastic, rubber, adhesive	10.0 for Plastic, rubber	0.3 (SML)	Used as nonfatty food contact materials (FCM) only; prohibited for the use of infant FCM
1,1-Dichloroethylene	75-35-4	Coatings, adhesive, paper and paperboard	–	5.0 (QM) ND (SML, DL = 0.05 mk/kg)	–
Cyclooctene	931-88-4	Paper and paperboard	–	0.05 (SML)	Used as nonfatty food contact materials (FCM) only

Adapted from GB 9685-2008 “Hygiene Standards for Uses of Additives in Food Containers and Packaging Materials.”

related national safety standards should be formulated and promulgated regularly according to the relevant rules in the national food safety standards.

To implement the related requirements of the Food Safety Law, the Chinese NHFPC issued its Management Rules for the Administrative Approval of New Varieties of Food-Related Products (the Rules) on 24 March 2011. The Rules set out procedures and requirements for the submission of petitions to clear the use of resins and additives in food packaging materials. Article 3 of the Rules sets out the requirements for petitions regarding food-related products. Specifically, the petitions should have a clear scope of use, demonstrate technical necessity, should not negatively impact human health under ordinary/reasonable use or alter the ingredients, structure, color, or flavor of the food, and should be used at the lowest possible level to achieve the desired technical effect. In particular, the Rules require petitions to include the following materials and information:

1) Application form
2) Physicochemical properties
3) Technical necessity, use, and conditions of use
4) Manufacturing process
5) Quality specifications, testing method, and test report
6) Toxicological safety assessment
7) Migration and/or residual level, estimated dietary exposure, and the method of determination
8) Approvals in other countries along with relevant documentation
9) Other materials that may benefit the evaluation.

The Chinese NHFPC has also released accompanying guidance (Guidance), which details data requirements not specified in the Rules. The quantity of toxicology data required for a given substance is based upon its projected level of migration. In summary:

1) If the migration value is less than 0.01 mg/kg, then only structural analysis and other safety data or literature are required.
2) If the migration value is between 0.01 and 0.05 mg/kg, then three mutagenicity studies are required (i.e., Ames test, *in vitro* mammalian chromosome aberration test, and bone marrow cell micronucleus test).
3) If the migration value is between 0.05 and 5.0 mg/kg, then three mutagenicity studies are required, as well as a sub-chronic oral feeding study in a rodent species.
4) If the migration value is between 5.0 and 60 mg/kg, then three mutagenicity studies, a sub-chronic oral feeding study in a rodent species, a teratogenicity study, a two-generation reproductive and developmental toxicity study, and a chronic toxicity and carcinogenicity bioassay are required.
5) For polymers with higher molecular weight (more than 1000 daltons), toxicity data for their monomers and other starting materials should be submitted.

35.2.3 Improvement of the Regulations and Standards Profile

Although the currently available regulations and standards have basically covered almost all kinds of food contact materials and articles, they are not good enough in that: (i) there are no related standards for new resins, lubricants, and adhesives; (ii) there are no unified requirements on food simulants, testing conditions, and migration or residues limits for potential hazards in the currently valid standards; (iii) declaration of compliance simply depends on laboratory testing results and there is no method to detect the specific migration levels for many substances; and (iv) it is not explicit whether polymerization reaction aids (such as catalyzers) and solvents should be subjected to the authorization procedure. Given the above-mentioned problems and according to the Food Safety Law, the NHFPC requires the cleanup and integration of all the food safety standards dating from 2010, based on which of the myriad of food packaging standards has been basically established in China. Details are listed in Figure 35.1 [6].

According to the scope of their application and characteristics, the national food safety standards can be classified into four categories: generic standards, product standards, procedure standards, and testing method standards. As an initially established project, the General Safety Principals for Food Contact Materials and Articles (to be issued) belongs to a framework regulation that is applicable to all food contact materials and articles. It mainly defines the basic requirements, limitation requirements, compliance principle, and statement of traceability and compliance concerning food contact materials and articles. In addition, it initially sets up the concept of a “functional barrier,” which preliminarily lays the foundation for establishing a supervision threshold. By using the measures of transmitting information about potential hazard substances on the food packing supply chain in developed countries, it solves the dilemma of no testing method for most restricted substances. The China National Standard (GB 9685-2008) Hygiene Standards for Uses of Additives in Food Containers and Packaging Materials made reference to standards in the US and the EU [7]. The new substances listed in the related notices have been integrated to the amended GB 9685 Standard, which has adopted a number of new provisions and principles. For example, among other changes, the revised Standard now permits the use of certain direct food additives (i.e., those listed in

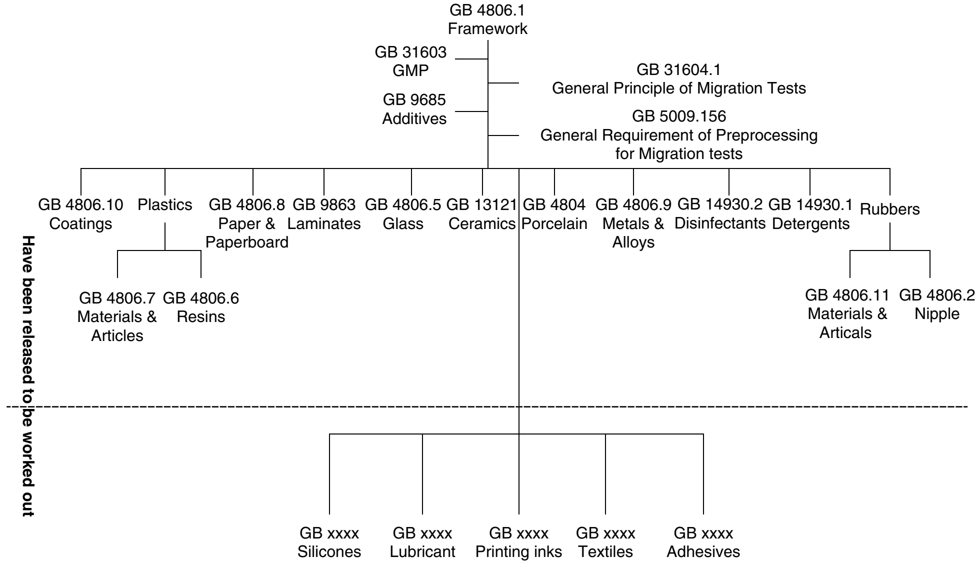


Figure 35.1 Profile of national safety standards for food contact materials and articles in China.

Table A.2 of GB 2760) provided that they do not migrate into foods in quantities having a technical effect on the final foods. In addition, the draft amendment would permit the use of the sodium, potassium, and calcium salts of GB 9685-listed acids, alcohols, and phenols. These provisions will relieve the pressure on the work of administrative approval without derogation of food safety. The recently issued standards General Principals for Migration Testing of Food Contact Materials and Articles (GB 31604.1-2015) sets detailed specifications on food simulants, testing conditions, and repeatedly used articles for migration testing and so on. Aside from GB 9685 and the above-mentioned standards, the Chinese competent authorities continue to revise and establish a number of other Food Safety Standards relevant to food packaging. Given the myriad of food packaging standards, there are regulations for the control of specific types of food contact materials, such as plastic, paper, ceramic, and stainless steel. The Plastic Resins for Food Contact Use and the Plastic Materials and Articles for Food Contact Use under clean-up and revision have harmonized the SMLs and/or residue limits on restricted substances and set OMLs for final plastic materials and articles, thus solving the problem of no standards for finished products made from the large number of new resins approved in the notifications.

35.3 Safety of Some Food Contact Substances

When hazardous substances migrate from food contact materials into foodstuffs up to a certain level, they will affect food safety and pose a potential hazard to human health. To prevent and control the influence of some substances in food packaging materials on food safety and sensory properties, both the US and the EU have very complex regulations covering the raw materials and additives that can be used in the manufacture of food contact materials. When necessary, these regulations also establish restrictions, such as migration limits and residue limits of chemical substances. The purpose of controlling the maximum dosage and residue limit is to control the level of migration, knowing that although residues of chemicals in food contact materials is an important factor affecting the quantity of chemical migration, only those chemicals that undergo migration could affect food safety. The amount of total migration refers to the total amount of substances that migrate from the food contact material to the food.

The overall migration limit (OML) means the maximum permitted amount of non-volatile substances released from a material or article into food simulants; the purpose of controlling the OML is to avoid the effect of the migrating substance on the sensory properties of the food and to prevent the migration levels of toxic and harmful substances from exceeding a certain limit. The level of overall migration cannot directly reflect the safety of the material concerned. The EU plastic regulations set out the OML as $10mg/dm^2$ or 60mg/kg (for infant foods) [7]; the US FDA defines the amount of total migration (or extraction) of polymer materials as $0.5 mg/in^2$ ($7.75 mg/dm^2$ or 50 mg/kg) [8]; and the Chinese standard for plastic finished products specifies the amount of overall migration (or evaporating residue) as not exceeding 30 mg/L or $6 mg/dm^2$. The level of specific migration refers to the amount of a particular chemical migrating from the food packaging material into the foodstuffs, and the maximum permissible level of migration for a chemical is also known as the specific migration limit. The level of specific migration directly reflects the safety of the final materials or articles. Related regulations in the US and the EU have set specific migration limits on hundreds of chemicals. The currently available standards and announcements in China have set out SMLs (or residues limit and the maximum dosage) on more than 80 varieties of resin monomers and other starting materials. Although more resins and additives have been permitted in recent years, there is still a big gap compared with the actual market requirements and other countries. The following sections cover several chemicals used in food contact materials and articles that have attracted increased attention in recent years.

For chemicals in food contact materials that have potential adverse effects (e.g. bisphenol A (BPA) and phthalates), particularly on infants and young children, both Mainland China and the EU have set some specific restrictions on their usage.

35.3.1 Bisphenol A (BPA)

BPA (2,2-bis(4-hydroxyphenyl) propane) is an organic chemical used in the manufacture of polycarbonate (PC) plastics and epoxy resin coatings. It also used in polyester, polysulfone, and polyacrylate resins. PC is used for manufacturing food and liquid containers, such as tableware (plates and mugs), microwave ware, cookware, and reservoirs for water dispensers. BPA-based epoxy phenolic resins are used as protective linings for food and beverage cans and as a coating on residential drinking water storage tanks and supply systems. Additionally, BPA may be used upstream in the process of manufacturing some raw materials, which are then used to produce food contact materials.

Based on a 2008 report by the National Toxicology Program (NTP), which found "clear evidence" of developmental toxicity at high doses of BPA, the USFDA released a document titled Draft Assessment of Bisphenol A for Use in Food Contact Applications. Although the reassessments indicated a need to further evaluate a number of endpoints or biological outcomes, concern was raised because potential toxic and hormonal properties of BPA have been found in recent years. Since then, the FDA has continued to review additional studies as they become available, including those addressing possible low-dose effects. In 2013, the USFDA amended its regulations to no longer provide for the use of BPA-based polycarbonate resins in baby bottles and sippy cups, and BPA-based epoxy resins as coatings in packaging for infant formula, in response to a food additive petition that demonstrates these uses of BPA as a food additive have been permanently and completely abandoned [9]. In Canada, BPA was assessed under the federal government's Chemical Management Plan (CMP) in 2008 and BPA was considered to meet the criteria for a substance capable of having harmful effects on the environment and human health. As a result, the government announced in 2009 that it would move forward with proposed regulations to ban the importation, sale, and advertising of polycarbonate baby bottles made with the BPA monomer. The use of BPA in polycarbonate infant feeding bottles was restricted by the EU and China in 2011.

However, the most concerns have been related to the hormonal activity of BPA and potentially related effects on neurological and behavioral development, prostate and mammary gland development in fetuses, infants, and children at current extremely low doses of BPA exposure. The safety of BPA has become a subject of much debate and has attracted much public attention. Consequently, continuous risk assessments of BPA have been conducted by the USFDA, the EFSA, the WHO/FAO and other agencies in recent years.

Actually, a number of effects of BPA in animals have been extensively investigated, and target organs identified in repeat-dose animal studies include intestine, liver, and kidney, but the presence of low-dose effects was not confirmed. According to the USFDA, a draft assessment in 2008 estimates that BPA exposure from use in food contact materials in infants and adults is 0.2–0.4 (2.42) μg/kg body weight (b.w.)/day and 0.1–0.2 (0.185) μg/kg b.w./day, respectively. The FDA (in 2008) and the EFSA (in 2006) set an identical tolerable daily intake (TDI) for BPA at 0.05 mg/kg b.w./day, with liver toxicity as the most sensitive endpoint. This is based on a no-observed-adverse-effect level (NOAEL) of 5 mg/kg b.w./day that has been identified in two multi-generation reproductive toxicity studies in rodents. It has been concluded that current levels of exposure for any age group from the use of BPA in food contact materials are much lower than the TDI.

In an updated risk assessment report issued by the EFSA in 2015, exposure was assessed for various groups of the human population in three different ways: (i) external exposure; (ii) internal exposure; and (iii) aggregated exposure (from diet, dust, cosmetics, and thermal paper) [10]. The estimated BPA dietary intake was the highest in infants and toddlers (up to 0.875 μg/kg b.w./day). Women of childbearing age had dietary exposures comparable to men of the same age (up to 0.388 μg/kg b.w./day). The highest aggregated exposure of 1.449 μg/kg b.w./day was estimated for adolescents. A benchmark dose (BMDL10) of 8960 μg/kg b.w./day was calculated for changes in the mean relative kidney weight in a two-generation toxicity study in mice. No BMDL10 could be calculated for mammary gland effects. Using data on toxicokinetics, this BMDL10 was converted to an HED of 609 μg/kg b.w./day. A total uncertainty factor of 150 was applied to establish a temporary tolerable daily intake (t-TDI) of 4 μg/kg b.w./day. It was concluded that there is no health concern for any age group from dietary exposure and low health concern from aggregated exposure.

35.3.2 Styrene

The primary use of styrene is in the manufacture of polystyrene (PS), acrylonitrile-styrene (AS), and acrylonitrile-butadiene-styrene (ABS) copolymers. PS is extensively used in the manufacture of plastic packaging, refrigeration equipment, and disposable cups and containers. In addition to its use in making polystyrene, styrene is naturally present in foods, such as strawberries, beef, beer, and cinnamon, and is naturally produced in the processing of foods such as wine and cheese [11, 12]. Hence, the source of styrene should be analyzed after it is detected in food.

A report on the safety of styrene-based polymers for food-contact use, submitted by the American Chemistry Council to the USFDA in 2013, provided an update on estimated dietary exposure to styrene from the use of polystyrene food-contact articles in the United States. As described in detail in a toxicological review of styrene submitted to the FDA by the Styrene Information and Research Center on 18 November 2002, the acceptable daily intake (ADI) for styrene is considered to be 90 000 μg/person/day. The dietary concentration of 2.20 ppb of styrene attributable to food packaging using the FDA's default assumes that an individual consumes a daily diet of 3.0 kg of food (all solids and liquids), resulting in an estimated daily intake (EDI) of 6.6 μg/person/day (0.0066 mg/person/day). Therefore, the calculated EDI (6.6 μg/person/day) is less than the ADI by more than four orders of magnitude.

The Centre for Food Safety (CFS) in Hong Kong conducted a study to assess the safety of containers used to hold instant cup noodles in 2009 [13]. Thirty sets of cup and lid were tested for total migration. All detected levels were well below the limit of 0.5 mg/ in^2 set by the FDA. A total of 11 cups and 5 lids (made from polystyrene, expanded polystyrene, or containing a polystyrene coating) were tested for styrene monomer. The levels of styrene monomer ranged from not being detected to 1000 mg/kg of the sample (i.e. 0.1%), which were within the limit of 0.5% of total residual styrene monomer set by the FDA. The NTP and the International Agency for Research on Cancer (IARC) have determined that polystyrene is safe for use in foodservice products.

Moreover, The IARC classifies styrene as possibly carcinogenic to humans (Group 2B) based on limited evidence in both humans and experimental animals. Styrene monomer is on the positive list in EU regulations for plastic materials and articles intended for contact with foodstuffs and without any limits. In China, hygiene standard for polystyrene resin used in food packaging (GB 9692-88) specifies a residue limit for styrene of 0.5%, equivalent to the limits in the provisions of the USFDA.

35.3.3 Plasticizers

Plasticizers are a kind of chemical with low molecular weight and can migrate from packaging materials into packaged food. Plasticizers such as phthalate, adipate, phosphate, citrate ester, and epoxide compounds are commonly used in polyvinyl chloride (PVC), polyvinyl alcohol (PVA), polyethylene (PE), and PS to improve plasticity, flexibility, and strength. The potential health concerns are mainly involved with phthalates, which interfere with the human endocrine function. The primary sources of phthalate in food are from the migration of packaging materials and contaminated environments.

An incident in which liquor was contaminated with plasticizer attracted public attention in China in December, 2012. The investigation showed that the main cause was the migration of bis(2-ethylhexyl) phthalate (DEHP) and di-butylphthalate (DBP) from plastic gaskets and pipelines during the production of the liquor. In 2014, the China National Center for Food Safety Risk Assessment was commissioned by the CN NHFPC to evaluate the risk to human health from DEHP and DBP in contaminated liquor products and to issue a risk assessment report [14]. The report adopted a TDI of 0.05 mg/kg b.w. for DEHP and 0.01 mg/kg b.w. for DBP set by the EFSA. The TDI represents the tolerable amount of unavoidable contaminant in food that a person can ingest on a daily basis without appreciable health risk. Assuming that dietary exposure accounts for about 80% of total exposure, a tolerable daily amount for a 60 kg person would be 2.4 mg DEHP and 0.48 mg DBP. In order to protect consumers of liquor from the potential hazards of DEHP and DBP, a conservative estimate of the maximum limit of DEHP and DBP in liquor products should not exceed 7.3 mg/kg and 1.2 mg/kg for people whose daily liquor consumption is be more than 300 g (about 5% of the population). Therefore, levels of DEHP and DBP found in the liquor products of 5 mg/kg and 1 mg/kg, respectively, were considered to be acceptable and unlikely to pose any risk to the health of consumers.

In many countries, plasticizers as additives are strictly authorized and must be included in the positive list before their use in the manufacture of plastic materials and articles. There are five kinds of phthalates permitted by EU legislation in food-contact plastics (Regulation 10/2011 as amended), including DBP, DEHP, butylbenzylphthalate

(BBP), di-isononylphthalate (DINP), and diisodecylphthalate (DIDP). In the US, BBP, dicyclohexylphthalate (DCHP), dipentylphthalate (DPP), DINP and DIDP are authorized by the FDA (see 21 CFR 178.3740). In China, nine kinds of phthalates are approved and listed in GB 9685-2008, which are under revision and some highly toxic chemicals will be deleted from the list. The use of these phthalates is subject to restriction by pertinent regulation. The restrictions generally specify the scope of use, the maximum residue, and the SML for each compound.

35.4 Food Safety in the Use of Emerging Packaging Technologies and Materials

35.4.1 Active and Intelligent Packaging

Active and intelligent packaging are innovative packaging technologies that directly interact with the internal environment within the package to protect food from contamination or degradation (e.g. release of an antimicrobial or antioxidant), and convey information about the conditions of the food to the consumers, respectively [15, 16]. Examples of active packaging include oxygen scavenger and CO_2 emitters placed inside the packaging and antimicrobial agents released from the packaging material. A good example of intelligent packaging is a time-temperature indicator placed on packaging that warns consumers about the storage temperature and time of a packaged item during distribution. For both of these packaging technologies, chemicals are used, thus there is the possibility of either direct contact with packaged food or migration into packaged food during processing and/or storage, which brings potential food safety hazards.

For ensuring food safety when using these advanced packaging technologies in the US, chemicals or any substances added to the packaging should follow the US Code of Federal Regulations (CFR) (21 CFR Part 174.5) General Provisions Applicable to Indirect Food Additives. This regulation specifies that the additives should not exceed, where no limitations are specified, amounts required to accomplish the intended physical or technical effect in the food-contact article. While no additional regulatory concerns exist for additives used in active packaging, it is important that manufacturers account for any additional migrants, decomposition by-products, or impurities that may occur as a result of the chemical activity in the active packaging material during its storage and shelf-life [17].

35.4.2 Edible Packaging

Edible packaging includes edible coatings and films that are prepared from edible materials, such as proteins, polysaccharides, or lipids. Edible coatings are applied to or made directly on foods, while edible films are independent structures. These coatings and films can improve overall food quality and extend shelf-life by functioning as barriers to moisture, gas, and solute transmission. Moreover, they can be used to incorporate functional food substances, such as antimicrobials, antioxidants, flavorings, and nutrients, to improve safety, stability, and sensory and nutritional properties of foods [18, 19]. Because they are an integral part of the edible portion of food products, assuring the food safety of the coating/film materials and their manufacturing processes is critically important. According to the US regulations for Food Additives Permitted for Direct Addition to Food for Human Consumption, 21 CFR172, sub-part C, any compound included in the formulation should abide by all regulations required for food ingredients, that is, should be generally recognized as safe (GRAS) or regulated as a food additive, and used within specified limitations. All coating and film-forming components, as well as any functional additives in the coating and film-forming materials, should be food-grade and nontoxic, and all process facilities should meet high standards for ensuring food safety.

Another important food safety issue pertinent to edible coatings and films is the presence of allergens, since many are made from allergenic substances, such as milk, soy, and wheat proteins or shellfish derivatives (chitosan). US food labelling regulations require that the presence of a known allergen used within a coating and film must be clearly labelled.

35.4.3 Biodegradable Packaging

Due to growing environmental concerns and increasing petroleum costs, the demands on sustainable and biodegradable packaging have been continuously increasing. Biodegradable packaging materials are those derived primarily from renewable sources, such as replenishable agricultural feedstock, animal sources, marine food processing industrial waste, or microbial sources, and can break down to produce environmentally friendly products, such as carbon dioxide, water, and quality compost [20]. Some of the most well-known and accepted biopolymers are cellulose, starch, polylactic acid (PLA), and gelatin. Each of these materials has its own properties, and has been used to manufacture various packaging for a wide range of food products.

When biodegradable packaging is used for packaging food items, it is a food contact-substance according to FDA regulations, and thus must abide by FDA regulations on packaging and food contact substances (FCSs) on safety, defined as "reasonable certainty in the minds of competent scientists that a substance is not harmful under the intended conditions of use" (1 CFR 170.3(i)). Tests should be carried out to ensure that biodegradable food packaging is not hazardous to humans and animals according to toxicological, environmental, and chemical indicators. Only when it is determined that a material presents no discernable health hazards, can it be used for packaging food.

35.4.4 Nanomaterials Used in Food Packaging

Nanomaterials with particle sizes in the range 1–100 nm have been used in food packaging, offering some exciting benefits to the food industry. The introduction of nanoparticles of clay into packaging improves gas and water barrier properties by blocking oxygen, carbon dioxide, and moisture from reaching the food. Nanoparticles of silver or titanium dioxide in packaging can prevent spoilage of foods. In addition, nanomaterials are used in intelligent (smart) packaging as biosensors, responding to environmental conditions, repairing themselve, or alerting a consumer to contamination or the presence of pathogens. However, the potential migration of nanomaterials from the packaging into the food and negative impacts on the safety or quality of the food are major safety concerns [21–23]. While there are ongoing studies to investigate the safety consequences of nanoparticles entering the human body and the environment, understanding exactly how these particles act in human body, how and if they are absorbed by different organs, and how the body might metabolize and eliminate/excrete them is still limited [24, 25]. The successful and safe implementation of nanomaterials in food packaging requires a constant dialogue between researchers, industry, and regulatory agencies.

35.5 Challenges and Strategies for Ensuring the Safety of Food Packaging

It is clear that food packaging is an important component of the food safety system. Food packaging may potentially lead to several food safety hazards, such as migration of chemical contaminants from packaging materials into food, allergenic compounds from some edible coating and film materials, recontamination by microorganisms as the result of packaging failures, and hard/sharp substances from broken packaging. Therefore, ensuring the safety of food packaging during the manufacturing process and in the supply chain is extremely important. Unfortunately, it is not an easy task as the industry and government agencies face several major challenges as briefly described below:

1) Lack of understanding of the scope and impact of chemical contaminants from different packaging materials and packaging systems. Hence, it is difficult to estimate the risk of chronic ingestion of contaminants from food packaging.
2) Limited understanding of the toxicity and safety of new materials, especially the different types of nanomaterials. These tests are time consuming and expensive, and there is even a lack of sufficient tools to test the potential hazards of nanomaterials by the oral (food) route and the potential migration of nanomaterials from packaging into food. Also, each type of nanomaterial has unique chemical and physical properties, which may result in completely different toxicity profiles and mechanisms. Hence, risk assessments of nanoparticles need to be conducted on a case-by-case basis [26].
3) Contamination during the packaging manufacturing process and in the supply chain, and human errors all potentially contribute to food safety hazards in food packaging. Poor sanitation conditions and practices, recontamination in the supply chain, and workers' health and hygiene can all result in unsafe food packaging.

To assure the safety of food packaging, first, awareness should be increased of potential risk factors associated with food packaging in the whole packaging chain from processing to consumers. Effective programs for reducing food safety risks at each point of manufacturing and distribution should be developed and implemented. Education and law enforcement are also essential for implementing correct practices in developing and applying safe packaging materials and technology. Continuous development, testing, and validation of safe, nontoxic packaging materials and technologies are necessary to ensure the safety of packaging. More research should be done in risk assessment of potential contaminants migrating from packaging materials, especially nanomaterials. Also, law enforcement of regulations on the use of direct and indirect additives in food packaging should be enhanced to provide a globally recognized food safety standard applied to packaging materials.

References

1 Bhunia, K., Sablani, S.S., Tang, J., Rasco, B. 2013. Migration of chemical compounds from packaging polymers during microwaving, conventional heat treatment, and storage. *Comprehensive Reviews in Food Science and Food Safety*, 12(55), 523–545.

2 The State Council of the People's Republic of China, jointly formulated by five ministries and bureaus. 1965. The "Provisional Regulations for Food Hygiene Management" (State Council (65) GUO-WEN-BAN-ZI No.304) [in Chinese].

3 EFSA. 2005. ESFA undertakes risk assessment on ITX. European Food Safety Authority Press Release 24 November, 2005. http://www.efsa.europa.eu/en/press/news/afc051124.htm (accessed November 2016).

4 EFSA. 2007. Scientific statement of the panel on food additives, flavourings, processing aids and materials in contact with food on a request from the Commission related to an update on the hazard assessment of 2-isopropyl thioxanthone (ITX) in food contact materials. http://www.efsa.europa.eu/en/efsajournal/pub/1064 (accessed November 2016)

5 Jen, J., Chen, J. 2016. *Food Safety in China: Past, Present and Future*. Beijing: China Science and Technology Press, 2016: 444 [in Chinese].

6 Jen, J., Chen, J. 2016. *Food Safety in China: Past, Present and Future*. Beijing: China Science and Technology Press. 2016: 447 [in Chinese].

7 EU. 2011. Commission Regulation (EC) No 10/2011 of 14 January 2011 on Plastic materials and articles intended to come into contact with food, OJ L 12, 15.1.2011, p. 1.

8 USFDA. 2014. CFR (Code of Federal Regulation), Title 21, Parts 177, Polymers, 239–362.

9 USFDA. 2015. Bisphenol A (BPA): Use in food contact application. www.fda.gov/food/ingredientspackaginglabeling/foodadditivesingredients/ucm064437.htm (accessed November 2016).

10 EFSA. 2015. Scientific opinion on the risks to public health related to the presence of bisphenol A (BPA) in foodstuffs: Executive summary, *EFSA Journal* 13(1), 3974.

11 NTP-CERHR. 2006. *Monograph on the Potential Human Reproductive and Developmental Effects of Styrene*, Washington, D.C.: US Government Printing Office, NIH Publication No. 06-4475, 7–28.

12 NTP. 2008. Final report on carcinogen background document for styrene, 32–38. http://cerhr.niehs.nih.gov/chemicals/bisphenol/bisphenol.pdf (accessed November 2016).

13 Centre for Food Safety, Hong Kong. 2009. Safety of instant cup noodle containers probed. http://www.fehd.gov.hk/english/news/details/07-05-2009-2144.html (accessed November 2016).

14 CN NHFPC. 2014. The risk assessment report on DEHP and DBP in contaminating liquor products in 2014. http://www.nhfpc.gov.cn/sps/s3586/201406/508888b1443a4ab4847380334a7745b1.shtml (accessed November 2016) [in Chinese].

15 Pereira De Abreu, D.A., Cruz, J.M., Losada, P.P. 2012. Active and intelligent packaging for the food industry. *Food Reviews International*, 28, 146–187.

16 Realini, C.E., Marcos, B. 2014. Active and intelligent packaging systems for a modern society. *Meat Science*, 98(3), 404–419.

17 Ettinger, D. J. 2002. Active and intelligent packaging: A US and EU Perspective. http://www.packaginglaw.com/2558_.shtml (accessed November 2016).

18 Duncan, T.V. 2011. Applications of nanotechnology in food packaging and food safety: Barrier materials, antimicrobials and sensors. *Journal of Colloid and Interface Science.* 363(1), 1–24.

19 EFSA. 2009. The potential risks arising from nanoscience and nanotechnologies on food and feed safety. *EFSA Journal*, 958, 1–39. http://www.efsa.europa.eu/en/efsajournal/pub/958 (accessed November 2016).

20 Lin, D., Zhao, Y. 2007. Innovations in the development and application of edible coatings for fresh and minimally processed fruits and vegetables. *Comprehensive Food Science and Food Safety*, 6, 60–75.

21 Munro, I. C., Haighton, L. A., Lynch, B. S., Tafazoli, S. 2009. Technological challenges of addressing new and more complex migrating products from novel food packaging materials. *Food Additives and Contaminants*, 26(12), 1534–1546.

22 Rhim, J.W, Park, H.M., Ha, C.S. 2013. Bio-nanocomposites for food packaging applications. *Progress in Polymer Science*, 38, 1629–1652.

23 Robertson, G.L. 2013. Edible, biobased and biodegradable food packaging materials. *Chapter 3 in Food Packaging: Principles and Practice*, 3rd edn. Boca Raton, FL: CRC Press, 49–90.

24 Silva-Weiss, M. Ih, Sobral, P. J. A., Gómez-Guillén, M. C., Bifani, V. 2013. Natural additives in bioactive edible films and coatings: functionality and applications in foods. *Food Engineering Reviews*, 5(4), 200–216.

25 Silvestre, C., Duraccio, D., Cimmino, S. 2011. Food packaging based on polymer nanomaterials. *Progress in Polymer Science*, 36, 1766–1782.

26 Taylor, M.R. 2008. *Assuring the safety of nanomaterials in food packaging: The regulatory process and key issue*s. PEN 12, July 2008.

36

Nanotechnology Applications to Improve Food Safety[a]

Boce Zhang[1], Yaguang Luo[1] and Hongda Chen[2]

[1] *Department of Clinical Laboratory and Nutritional Sciences, Lowell, USA*
[2] *National Institute of Food and Agriculture, US Department of Agriculture, USA*

36.1 Introduction

Food-borne illness remains one of the top global public health challenges today. Even the US food supply – widely regarded as one of the safest – it is far from immune from food-borne outbreaks. According to the Centers for Disease Control and Prevention (CDC) estimation, consumption of contaminated foods causes 9.4 million illnesses every year in the US alone. In 2014, 864 food-borne disease outbreaks were reported, resulting in 13 246 illnesses, 712 hospitalizations, 21 deaths, and 21 food recalls [1]. Globally, food-borne diseases result in an estimated two million deaths annually [2]. Beyond the direct physical and emotional suffering of the victims and their families, food-borne illness outbreaks lead to significant burdens on society, including loss of work productivity, tremendous financial losses to food industries, and loss of consumer confidence in the ability of agriculture and the food system, and government to ensure a safe food supply. In a recent poll conducted in China, food poisoning has emerged at the top of the list of consumer concerns, with more than 80% of the population projected as worrying about the safety of their food supply [3, 4]. China's share of global agricultural markets has also been impaired by its food safety outbreak record. China's food export has been reduced over the years, with shipments of produce and seafood rejected for falling short of the stringent standards of the recipient countries. A gap in food safety standards, implementations and controls is apparent between China and its international partners.

Microbial and chemical contaminations are the most frequently reported problems among all food safety challenges in China, as well as globally [5]. Therefore, this chapter highlights the applications and implications of nanotechnology in problem identification and solution development for microbial and chemical-related food safety challenges.

---

[a] The views expressed in this chapter are those of the authors. They are not necessarily those of the United States Government, or the National Institute of Food and Agriculture (NIFA) or the Agricultural Research Service (ARS) of the US Department of Agriculture (USDA).

Food Safety in China: Science, Technology, Management and Regulation, First Edition.
Edited by Joseph J. Jen and Junshi Chen.

Nanoscale science is an emerging frontier. Research into and development of nanotechnology have skyrocketed over the past 15 years. Nanomaterials, of particle size approximately 1 to 100 nm, often exhibit novel physical and chemical properties different from those of their macro-scale counterparts. Nanomaterial engineering renders the capability to precisely fabricate materials with superior functionalities that can lead to new applications and novel solutions to technical challenges. In 2008 alone, over $15 billion was invested to promote nanotechnology research, and more than 400 000 researchers were employed globally [6]. The nanotechnology market is estimated to project at least $3 trillion, and the industry could support at least 6 million workers by 2020 [6]. Research scholars and industrial stakeholders have all envisioned the convergence between nanotechnology, food science, and agriculture as revolutionary advances in the decades ahead. This chapter summarizes the two major areas of food safety applications of nanotechnology: detection of pathogens and hazardous contaminants using nanosensors, and intervention technologies using nanoscale delivery systems and engineered food contact materials.

36.2 Recent Advances in Nanotechnology Applications for Improving Food Safety

36.2.1 Identification and Detection of Pathogens and Hazardous Substances in Food

36.2.1.1 Advances in Electrochemical Nanosensors

Advanced disease diagnosis and pathogen detection in food and agricultural products serve as critical tools for crop and animal protection, food safety, and sustainable agriculture. Novel technologies have been invented for rapid detection of pathogens using electrochemical methods. The developments presented below include bionanocomposite-enhanced sensors, self-powered biofuel cells, and bio-microelectromechanical systems [7–10].

Bionanocomposite Sensors. Bionanocomposite-enhanced sensors have been developed for the rapid detection of pathogenic bacteria and fungi using electrochemical signals [7, 8] The schematic view of an electrochemical sensor is illustrated in Figure 36.1. The transfer of electrons from the enzyme-substrate reaction to the functionalized electrode generates the electrochemical signal. The concept of "bionanocomposite" refers to the combination of the enzymes, conductive nanomaterials, and polymeric matrices as mechanical supports [11, 12]. The detection specificity is due to the highly selective binding between the target substrate and the embedded enzyme. The analytes may include pathogenic cells, pathogen biomarkers, metabolites, volatiles, and other derivatives from pathogens or food hosts.

Incorporation of bionanocomposites into traditional enzyme-based electrochemical sensor platforms has drawn increasing attention among researchers. Some of the critical components in bionanocomposites are conductive nanomaterials, such as conductive polymers, metal nanoparticles [12, 13], grapheme nanosheets [14, 15], and carbon nanotubes (CNTs) [16, 17], which ensure instantaneous and sensitive signal conduction [18].

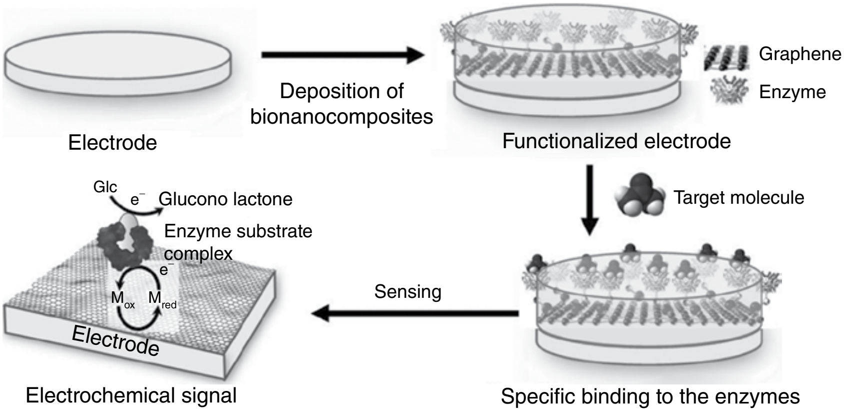


Figure 36.1 Schematic view of an electrochemical-sensing platform via bionanocomposite enhancement.

Polypyrrole (PPy) is one of the most widely studied conducting polymers in electrochemical biosensors. PPy can be used in bionanocomposites with exfoliated proteins, DNA oligomers, and other nano-scaled biomolecules [13, 18] Conducting polymers can also be functionalized via covalent or non-covalent bonding with bionanomaterials in the design of novel electrochemical sensors, [13] which possess catalytic or affinitive properties [19].

Metal nanoparticles are highly conductive and efficient for signal amplification, yet some have low biocompatibility that prohibits the attachment of antigens to antibodies. Among those with better attributes, zinc oxide (ZnO) and gold nanoparticles (GNPs) have been extensively studied. They are more biocompatible, easy to reproduce, highly conductive, and have high specific surface area and energy, as well as many adsorption sites. In addition, ZnO NPs and GNPs are often employed as stabilizers for biomolecules without distorting their bioactivity [20, 21]. Gold is one of the most commonly used metals to improve the conductivity and sensitivity of electrodes [21, 22].

Conductive carbons, including graphene nanosheets and carbon nanotubes (CNTs), are another conspicuous choice of new conductive materials in the development of bionanocomposites. Graphene consists of a monolayer of hexagonally packed and arranged carbon atoms. Graphene has a large surface area, good biocompatibility and mechanical properties, and superior thermal and electrical conductivities, thus making an ideal material for electrochemical sensing [23, 24]. Graphite powder and chitosan mixtures have been developed as electrode inks for *in situ* detection of electroactive toxins, such as methyl parathion and nitrite, on solid agricultural products [25]. CNTs can be viewed as rolled-up graphene sheets. CNTs (mainly multi-walled CNTs) are commonly functionalized by redox enzymes, thiol derivatives, hapten molecules, and N-ethyl-N-(3-dimethylaminopropyl)-carbodiimide-N-hydroxysuccinimide (EDS-NHS) (Figure 36.2) [21, 26]. Functionalized CNTs can also improve the direct electron transfer and signal transmission between the biological elements and the electrode.

The enzyme and analyte system is normally electrochemical in nature, where enzymes and other bioelectrochemical components serve as the primary transduction elements [25, 27]. The electrochemical signals can be captured and analyzed by amperometric, potentiometric, and/or conductometric devices.

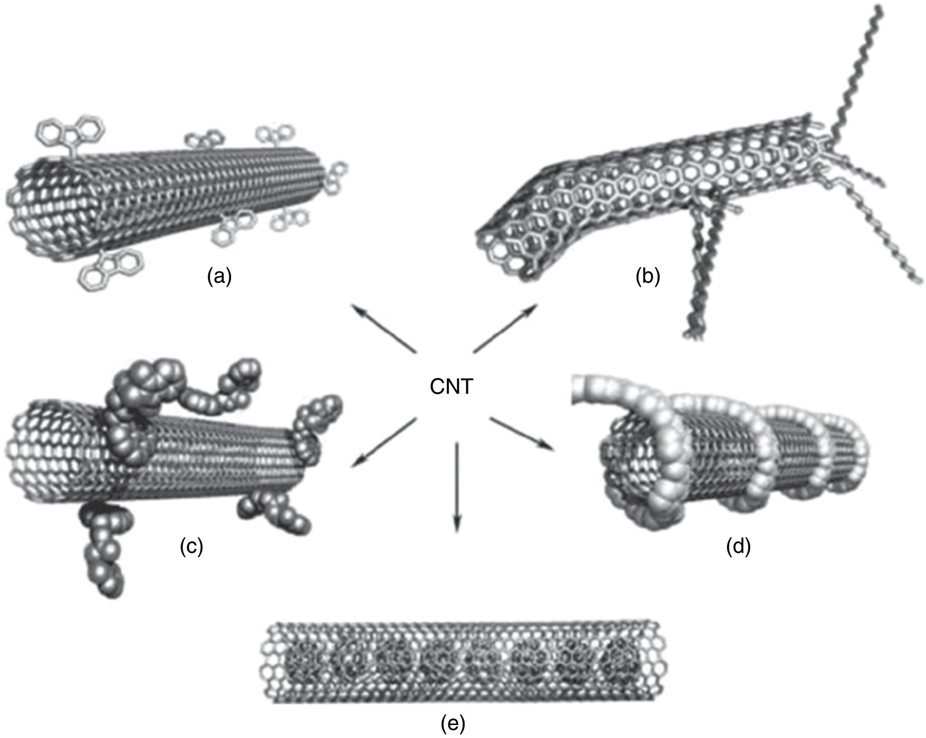


Figure 36.2 Different types of functionalized CNTs: (a) covalently functionalized sidewall; (b) functionalized defect-group; (c) noncovalent and exohedral functionalization with surfactants; (d) noncovalent and exohedral functionalization with biopolymers; (e) endohedral functionalization with C60 [26].

Bionanocomposites can also be incorporated into highly sensitive quartz crystal microbalance (QCM) systems. QCM measures the change in frequency (Δf) and resistance (ΔR), when analytes bind to recognized molecules, and deposit on an oscillating piezoelectric quartz sensing element. Microscale and nanoscale bionanocomposites, consisting of a magnet, silica, and polymer, are functionalized with antibodies for QCM-based immunosensors [28, 29]. Significant signal amplification has been achieved by the change in resonance frequency when spherical materials immobilize on bacterial cells [28, 29].

Biofuel Cells for Self-Powered Sensing. Bioelectronics corresponds to a field of biomolecular electronics that investigates the use of living organisms and subcellular components (including DNA, enzymes, and whole biological cells) in electronic devices [10, 30, 31]. In the past decade, considerable promise has been shown largely by self-powered biofuel cells (BFCs). BFCs are operated by biocatalysts to convert biochemical energy to electrical energy via oxidation of substrates (fuel). A major product of the oxidation is the catalytic separation of electrons from their parent molecules, which can create an electric current (Figure 36.3) [10].

The first self-powered BFC was reported in 2001 [32, 33], and made use of glucose oxidase. BFCs differ from conventional fuel cells because they use biocatalysts instead

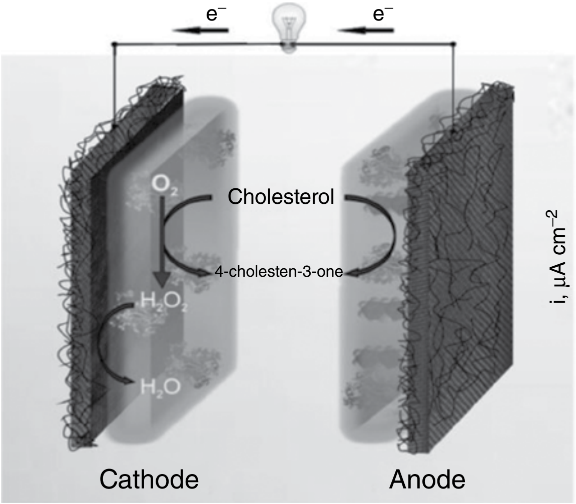


Figure 36.3 A biofuel cells for self-powered cholesterol sensing [36].

of traditional metallic electrocatalysts. BFCs are categorized into three groups: microbial BFCs employ the biopower of living microorganisms, organelle or mitochondrial BFCs are energized by subcellular components (organelles), and enzymatic BFCs, which are one of the most extensively studied groups, use an enzyme or cascade of enzymes to catalyze the oxidation of a substrate [32].

Progress has been made in proof of concept applications of BFCs for the detection of chemicals including natural nutrients and contaminants in food systems. Carbohydrates have been one of the most explored targets [10, 34]. The energy output on a BFC from the oxidation of glucose in fruit juices can be further developed as a self-powered glucose sensor. Another study successfully developed a nanocarbon anode for the detection of ascorbic acid [35]. In a recent study, monitoring of cholesterol in fluids (e.g., plasma or food extracts) has become feasible on a novel "single-enzyme, membrane-free" self-powered BFC with immobilized cholesterol oxidase (Figure 36.3) [36]. In another effort, a BFC has been developed for ultrasensitive sensing of immunoglobulin G (IgG), which is an important biomarker for food allergens [37]. BFCs are also potential solutions for rapid sensing of toxins and contaminants in food and agricultural products. Additional investigations have been conducted on the use of BFCs to monitor oxidative stress, herbicide residues, antibiotic residues, and biological cyanides, as well as heavy metal components [38–40]. These studies have demonstrated the capabilities and conceptual advancement of BFCs for food-safety-related applications. Nonetheless, more work is still needed to overcome several major technical hurdles, especially their short shelf life and poor power densities for practical applications.

Enzyme stability in biosensors is a challenging issue. Enzymes that specifically interact with target analytes can be coupled to biosensors that take a direct and rapid measurement in complex mixtures. Enzymes are macromolecular proteins, which consist of amino acids that are folded in very complicated structures. Arguably the most difficult challenge that prevents the development of practical enzyme-based biosensors is that enzymes lose their bioactivity over storage or usage. Many factors can impair the bioactivity of enzymes, including improper storage temperature, pH, solution, ultraviolet light, high pressure, and so on [41, 42]. The stability of enzymes depends in part on the balance between hydrophobic and hydrophilic groups within the protein. While most applications of high hydrostatic pressure (HHP) are developed for the inactivation of deleterious enzymes [41, 42], recent studies have discovered that HHP can also stabilize and increase the bioactivity of enzymes [43]. Chemical bonds between hydrophobic and hydrophilic groups in the enzyme, followed by attachment or encapsulation in nanofilms under HHP is expected to maximize the stability of the selected enzyme biosensors [44]. For instance, lipase is an extensively used enzyme for value-added product synthesis and modification, but it can easily lose stability and bioactivity above 40 °C. It is found that HHP in hexane can reduce the effect of thermal inactivation of lipases [45]. Deposition of polymeric materials in the biosensor has also been exploited as a positive strategy to improve enzyme stability in HHP [44]. Although there is no direct evidence that HHP can preserve enzyme activity in biosensors, existing reports have proven that the concept is very promising. Further research may focus on the stabilization of enzyme biosensors relevant to food and agriculture using a combination of nanoscience and chemical modification of enzymes under HHP.

Bio-Microelectromechanical Systems (BioMEMS). Viable cell count is an important parameter used to assess food quality and safety. Rapid detection methods using immunological and molecular recognition techniques are often limited in their ability to assay cellular viability and to distinguish between viable and nonviable cells [46]. Traditional culture-based tests that assess the number of viable cells require long assay times up to several days [47, 48]. Nanotechnology has enabled rapid viability assays using BioMEMS, which is an emerging platform for the development of viability test devices via either electrochemical or quorum sensing methods. BioMEMS systems can be modified with magnetic separation and immobilization to improve the reusability and durability of the device [49, 50]. The electrochemical detection targets the redox reaction and electron transfer in the pathogen's metabolic activity [51, 52]. Quorum sensing will adopt an advanced biological approach to detecting a pathogen's intercellular communication related to pathogenesis or virulence [9, 53].

The cell viability of bacteria can be detected and amplified via quantifying the electrochemical signals of cellular metabolites [52, 54]. The electrochemical system is employed to probe the redox interactions of the natural product pyocyanin (PYO), to shuttle electrons between viable bacterial metabolites and the catechol-functionalized electrode in a BioMEMS device [52, 54]. The electrochemical signal is detected and amplified via an imposed oscillating potential, which can engage redox cycling mechanisms that switch the electrode's redox state. These response characteristics suggest that natural phenolic compounds may be responsive to extracellular electron transport from bacterial anaerobic respiration and redox signaling, as well as redox effector action [52, 54]. The PYO-based amplification can be achieved via two substantially different mechanisms (Figure 36.4), namely chemical amplification with free PYO and biological amplification with metabolite PYO generated *in situ* by live opportunistic bacteria (e.g., *Pseudomonas aeruginosa*) [55]. In biological amplification, *P. aeruginosa* will produce PYO metabolites by induced cultivation, while chemical amplification simply relies on free PYO fed by an external source. This BioMEMS device could distinguish between live bacteria, which have metabolic activity, dead cells, which cannot produce redox metabolites, and

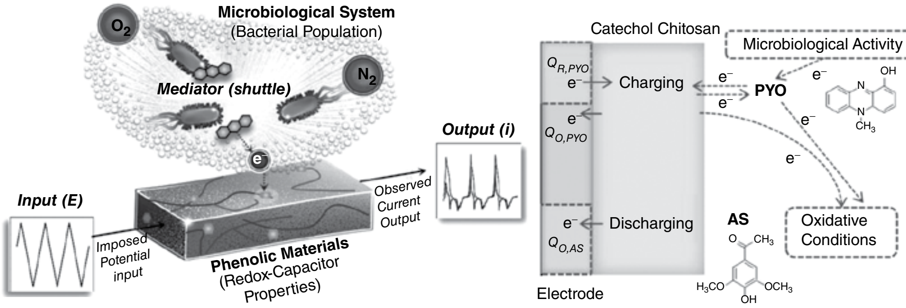


Figure 36.4 Electrochemical detection: amplification and detection of the electrochemical signal of viable bacterial cells [55].

thus generate no signal, and injured cells, which show an increased level of metabolic activity [51].

Another advance takes advantage of a unique biochemical signaling process – quorum sensing between viable bacterial cells on BioMEMS devices. The device consists of an engineered quorum sensing regulon so that individual cell signals (specifically, autoinducers, AI-2) can be used to guide high-level expression of the recombinant green fluorescent protein in an engineered *Esherichia coli* [9, 53]. This engineered *E. coli* acts as a reporter cell to sense the AI-2 generated by natural (viable) *E. coli*. AI-2 generated by target cells can trigger the expression of fluorescent proteins in reporter cells. The GFP engineered *E. coli* is the reporter cell expressing DsRed [9]. By visual inspection, the emergence of QS behavior (DsRed) was evident as early as 5 hours and reached a maximum at 11 hours. Although these new findings are still at an early stage of development, they provide evidence that both electrochemical and quorum sensing-based methods have a huge potential for practical applications to rapidly detect viable pathogens in food systems.

36.2.1.2 Advanced Optical Nanosensors

Nanotechnology has also facilitated the detection of food-borne pathogens using optical sensors. Significant improvements have been made over the past decade on Raman spectroscopy, surface plasmon resonance, ELISA, and DNA-based sensors [56–58].

Surface-Enhanced Raman Spectroscopy (SERS). SERS is a promising technique for the rapid, sensitive, and accurate detection of pathogens and contaminants in food products. The surface sensitive SERS technique employs rough metal surfaces or metallic nanostructures as analyte substrates, which promote amplification and enhancement of Raman scattering (Figure 36.5) [56, 59]. The fundamental mechanisms of the signal enhancement are still controversial. The two primary theories are electromagnetic and chemical. The electromagnetic theory suggests that the incident light can activate the plasma mode on the metal surfaces, which transmits the energy to the target molecule via dipole-dipole vibrations. After the energy is transferred back to the metallic surface, new photonic energy is emitted and scattered [60]. The chemical theory involves electron and charge transfer between the metallic surface and the chemisorbed analytes [60].

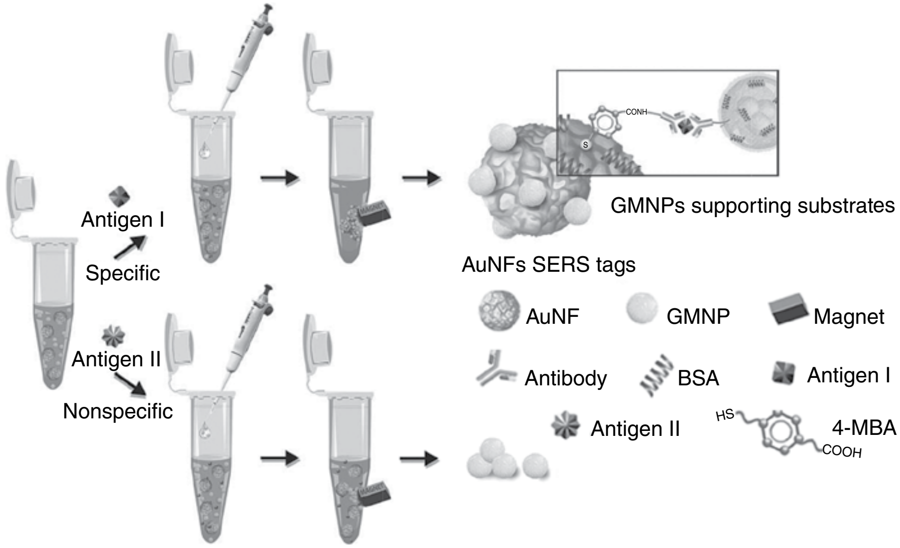


Figure 36.5 Schematic view of the gold nanoflowers (AuNFs) and SERS-based magnetic nanoparticles (GMNPs) as ultrasensitive detection of a biomarker [59].

Various metallic substrates have been exploited for different SERS applications among Chinese researchers. A well-performing substrate is crucial to the real-world applications of SERS [56]. Gold nanoparticles, nanorods, and silver NPs with particle sizes of 10–200 nm are among those most widely used colloid nanosubstrates, for rapid detection of food additives [61, 62]. Although colloid nanosubstrates can be easily and flexibly fabricated with customizable composition, size, and physiochemical properties, the primary limitation is poor reproducibility due to random aggregation and lack of structural fidelity and integrity [56].

Recent advances have targeted chemical contaminants, food adulterants, small molecular toxins, and other allergenic and protein toxins [63]. For instance, SERS has been explored as a feasible solution for the rapid detection of mycotoxin [56], aflatoxins [62], ochratoxin-A [64], saxitoxin [65], tetrodotoxin [66], microcystin [67], and other molecular toxins. In addition, SERS-based bacterial identification can be rapidly performed on biochemical signatures, while achieving a single cell detection limit [68]. However, most of the SERS methods have yet to be tested and evaluated on real food products, and the SERS instrumentation may be expensive for some food industry operations [56].

Surface Plasmon Resonance (SPR). SPR is the resonant oscillation of electrons stimulated by incident light at the interface between a metal (usually gold or silver) surface (sensor) and target materials (e.g., contaminants, pathogen cells) adsorbed onto the conducting surface. The SPR can be plasmonic in nature against subwavelength scale nanostructures [69]. The SPR detects changes in the refractive index caused by the binding of target analytes to the metallic sensor surface. The refractive index differences are responsive to the size of the target antigen and the conformation of the antibody-antigen complex during binding, which includes solvent reorganization and protein unfolding.

The change in the refractive index is detected as a shift in the angle of maximum reflection of the incident light on the metallic sensor surface [70].

The food safety-related applications of SPR instruments, in most cases, involve a layer of defined monoclonal or polyclonal antibodies [71]. The SPR directly detects changes in the refractive index upon binding to the target antigens. SPR-based immunosensors have been developed for the rapid detection of pathogens in different matrices. Examples of this approach are the detection and identification of *E. coli* O157:H7, *Salmonella spp.*, *Staphylococcus aureus*, and *Listeria monocytogenes* [70, 72] Another SPR-based strategy involves metabolic products as biomarkers for microbial agents, including Shiga toxin-2 from *E. coli* O157:H7, and enterotoxin B and virulence factors from *S. aureus* [71]. Figure 36.6 illustrates an inhibition assay for small molecular analytes. A sample containing the analytes (e.g., metabolites or toxins) is incubated with free antibodies to allow complex binding and formation. The mixture is then injected onto and immobilized on the sensor surface, which results in a change in mass and refractive index as SPR-responsive signals [73].

Indirect detection of pathogenic agents via the analysis of humoral immune response using SPR has not been widely developed for food safety applications. However, recent studies show the possibility that SPR-based technology can reveal the infection history of an animal or human subject. Humoral immunity is mediated by macromolecular antibodies instead of host cells, and these appear in extracellular fluids in the form of secreted antibodies, antimicrobial peptides, and complementary proteins [74]. Recent advances have exploited the capability of SPR to reveal the history of acquired or adaptive immunity. Infections with parasites, pathogenic bacteria, and human immunodeficiency viruses can be successfully identified in human and porcine sera, and avian eggs by antigen-functionalized SPR sensors [71].

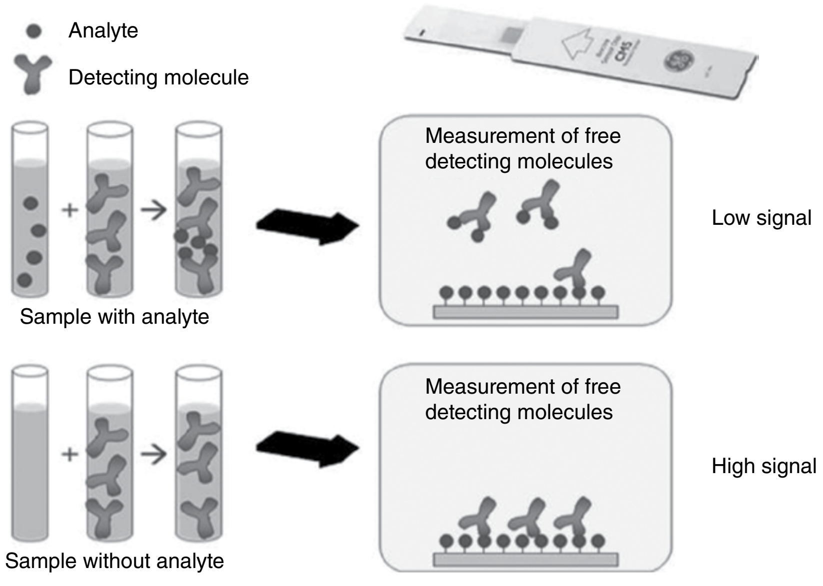


Figure 36.6 Inhibition assays for small molecular targets [73].

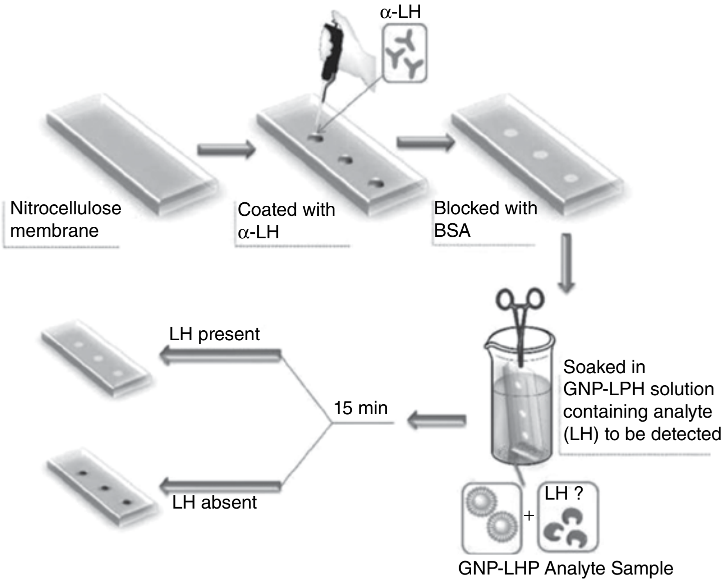


Figure 36.7 Schematic illustration of the MCN-based bionanosensor for the detection of luteinizing hormone [77].

Enzyme-Linked Immunosorbent Assay (ELISA). Recent advances in ELISA have been proven to be a promising technology for rapid on-site diagnosis of pathogens in food. The fundamental reaction is achieved by multicomponent nanomaterials (MCNs). For instance, gallium ions and biomolecules can be successfully grafted via thiol linkages onto the surface of gold nanoparticles (AuNPs), the most investigated chemicals for signal amplification of ELISA [75, 76]. This paves the synthetic route for an MCN-based immunosorbent assay for nanobiosensors. An example has been described for detecting luteinizing hormone (LH) in sheep using MCNs. Figure 36.7 illustrates the MCN, a new LH-targeting peptide (LHP) sequence, which has been immobilized on AuNPs as an ELISA-based nanosensor. In the absence of LH, the peptide coated on the nanosensor binds to the MCN, resulting in a distinctive red color. In the presence of LH, however, the peptide and LH bind in the solution system, and no color appears on the membrane [77]. The MCN-based nanosensor is a promising technique with simple, portable, cost-effective benefits for on-site food safety applications.

DNA-Based Nanosensors. Polymeric dendrimers have been extensively investigated and characterized for their potential applications in cell imaging, cell sensing, and delivery systems of various payloads [58, 78, 79]. A novel group of DNA dendrimers has recently been developed via controlled enzymatic ligation of Y-shaped DNA (Y-DNA), which exhibits simple fabrication steps, low cellular toxicity, and freedom to be either isotropic or anisotropic. The building block of Y-DNA is composed of three oligonucleotides, and each strand is partially complementary to another (Figure 36.8) [58, 80]. The dendrimer-like DNA (DL-DNA) is then formed by ligating three Y-DNA via the unpaired 'sticky ends' [58, 81]. The DL-DNA has adjustable size, structure and morphology by simply altering the composition of the individual strands in the Y-DNA. In addition, the

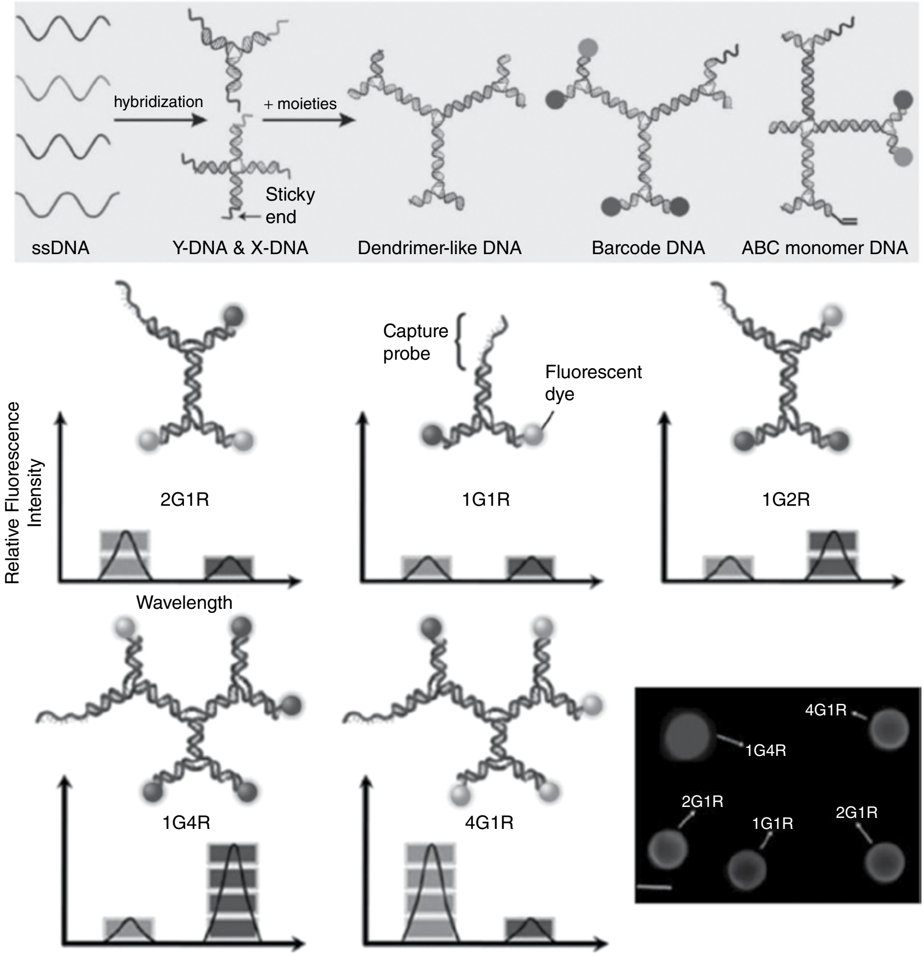


Figure 36.8 Schematic view of the formation of DL-DNA: Single-strand ssDNA is hybridized in DL-DNA, barcode DNA, and ABC monomer DNA (top); a barcode DNA-based multiplexed detection of pathogens (bottom) [58, 82].

DL-DNA can be functionalized to 'Barcode DNA' or 'anisotropic, branched, and cross-linkable (ABC) monomer DNA' by the fluorescent dye, capture DNA probe, and/or cross-linkable groups (Figure 36.8) to enhance cellular interface with the DL-DNA in biosensors [58, 82].

Figure 36.8 illustrates the concept of using a DNA barcode as a rapid and simultaneous identification of multiple pathogens in a single assay. Specifically, each DNA nanobarcode carries a unique ratio of fluorescent dyes and a segment of recognition unit that specifically detects and binds to pathogenic biomarkers [83]. Because the type and ratio of the fluorescent dyes on the DNA barcode can be precisely controlled, a simple multicolor decoding of the fluorescent signal can easily distinguish between specific pathogenic strains.

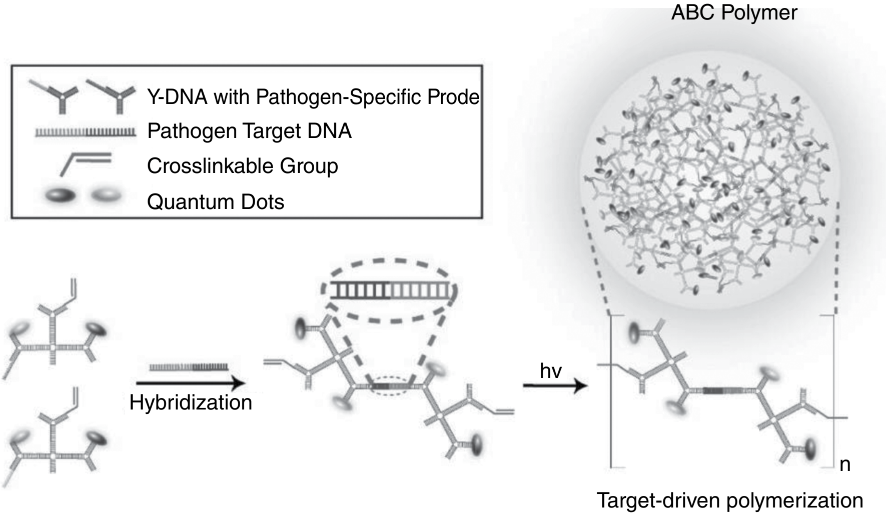


Figure 36.9 Schematic view of ABC monomers for rapid pathogen detection via the photopolymerization-driven amplification [85, 86].

In a more recent endeavor, the DL-DNA was further developed with photo-reactive units using ABC monomers [84]. The ABC monomers were synthesized via enzymatic ligation of Y-DNA by incorporating a photocrosslinkable moiety to the "sticky end" (Figure 36.9) [85, 86]. Similarly, the ABC monomers can be further functionalized by fluorescent dyes, quantum dots, gold nanoparticles, interfering RNA and siRNA, and so on [58, 87]. When these ABC monomers were built with a single-stranded oligonucleotide targeting pathogenic DNA, photopolymerization was achieved only in the presence of the target pathogen DNA. These ABC monomers achieved highly sensitive and specific sensing of target cells via light-driven amplification. After brief UV exposure, monomers polymerize into large aggregates that are easy to detect [58].

Other self-assembled 3D DNA nanostructures have been exploited by a Chinese group in an effort to overcome a major hurdle in biosensor development, the restricted accessibility to target analytes at the solid–water interface [78, 88, 89]. Engineered DNA nanostructures with thiol modification can self-assemble into tetrahedral structures on a gold surface with high reproducibility. The rigid DNA tetrahedra, with a highly ordered nanostructure, function as scaffolds to immobilize biomolecular probes (e.g., aptamers and antibodies) for biosensing development. Additionally, the DNA tetrahedral nanostructures significantly increase analyte accessibility, and thus improve the detection sensitivity of molecular analytes (DNA, RNA, proteins, and small molecules) in target cells by several orders of magnitude [78, 88, 89].

36.2.2 Preventive Control and Intervention Strategies

36.2.2.1 Nanoscale Antimicrobial Systems

Nanoparticle Delivery Systems. Recently, fabrication of antimicrobial nanoparticle delivery systems has been developed using a group of cationic antimicrobials (e.g., lauric arginate and polylysine) and anionic polymer nanostructures (e.g., pectin, gum Arabic, and carrageenan) [90–92]. While cationic lauric arginate (LAE) is effective in controlling negatively charged bacterial cells, its poor sensory attributes and instability in food matrices and the gastrointestinal tract limit its uses on food products. A nanotechnological approach has been employed to stabilize LAE with a novel antimicrobial delivery system, in which the LAE binds to anionic polysaccharides via electrostatic attraction. The nanodelivery system optimizes the benefits of LAE, such as low toxicity and high antimicrobial efficacy, while minimizing the detriments of dissatisfactory taste and instability [93].

Generally, the fundamental mechanism is electrostatic coacervation between positively charged active ingredients and negatively charged carrier materials, which can form colorless and transparent nanoparticle delivery systems [90, 94]. Such nanoparticles are particularly suited for drink and beverage applications. The stability and antimicrobial efficacy are determined by the fabrication conditions, including the molecular properties of the carrier biopolymer (e.g., charge density, degree of polymerization, structural conformation), as well as the ratio of the cationic antimicrobial to the anionic polymer [90–92]. Pectin and gum Arabic have been found to be the most effective polymeric materials in the formation and stabilization of cationic antimicrobial agents (Figure 36.10) [94].

The antimicrobial efficacy of the novel nanoparticle-based delivery system has also been evaluated in several *in vitro* studies. The cationic antimicrobial (by itself or in a nanoparticle delivery system) can inhibit the growth of two acid-resistant yeasts: *Zygosaccharomyces bailii* and *Saccharomyces cerevisiae*, which are related to food spoilage [90, 93], but no evidence has been found that the antimicrobial nanoparticle would be detrimental or toxic to the generic microbiota in the gastrointestinal tract, from

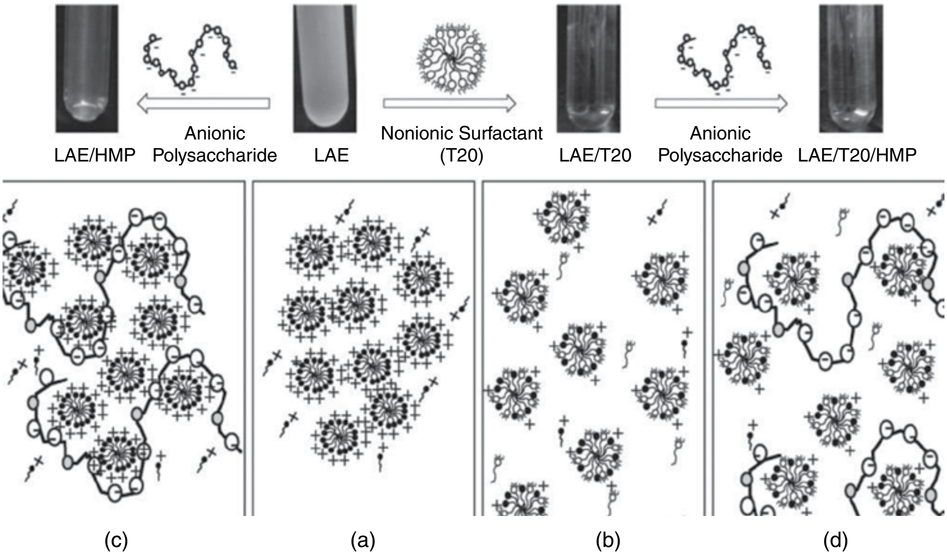


Figure 36.10 Scheme of the formation of pectin-based nanodelivery system for cationic antimicrobial agents: (a) LAE cationic micelles, (b) cationic LAE with nonionic Tween-20 micelles, (c) cationic LAE and anionic pectin, and (d) mixed cationic LAE, nonionic Tween-20 and anionic pectin in 50 mM Na-citrate buffer (pH 3.5) [94].

animal feeding studies. This is a highly desirable outcome as the well-established healthy microbiota within the GI tract is preserved with minimal disturbance. The preservation of the gut microflora is important to ensure health, as evident from the large body of recent scientific literature in microbiome investigations. More efforts have been made to improve the efficacy of the nanoparticle delivery system by incorporating essential oils to form multicomponent antimicrobial nanoparticles [91].

Nano-Dispersion Systems for Lipophilic Essential Oils. Essential oils are a group of food-grade antimicrobial agents that are prevalently accepted in food and agricultural products and practices. They are highly volatile aromatic chemicals, which are commonly extracted from different parts of a plant or herb, including bark, seeds, leaves, and stem. Essential oils have been long identified as excellent antioxidants and broad-spectrum antimicrobial agents against bacteria and fungi [95]. However, they have limited direct applications in food products, which is primarily attributed to their lipophilic nature and marginal solubility in water. They also have a tendency to bind with lipophilic proteins, lipids, and other nonpolar substances in food matrices, which often leads to an undesirable loss of antimicrobial efficacy [96, 97]. Therefore, ongoing research efforts have been directed towards developing delivery systems for these antimicrobials to improve their stability and promote controllable release via nano-dispersing methods [98].

Methods for nano-dispersion that have been used include encapsulation of essential oils in spray dried capsules made of conjugates of whey protein isolate (WPI) and maltodextrin (MD) [99]. The WPI-MD conjugates are reported to be a phenomenal amphiphilic material, which improves the stability of the essential oil and dispersability of the capsules in the aqueous phase. The physicochemical properties of the conjugates can be optimized by adjusting the WPI to MD mass ratio, the degree of polymerization, and the spray drying conditions [98]. The principle of the nano-dispersion method includes two steps. The first involves the emulsion-evaporation of the essential oil in the organic solvent with conjugates in the aqueous solution, followed by evaporation of the solvent via spray drying. The second step is to resuspend the dried powders in the aqueous solution to form nanoscale capsules. Capsules can be hydrated using various pH conditions and ionic strengths to optimize different characteristics and physicochemical properties, like particle size distribution, optical transparency, and thermal stability [97, 98].

The conjugate solids exhibit better antimicrobial efficacy, and lower toxicity, and manufacturing costs, compared to other existing preservation technologies, including microemulsion, nanoemulsion, and liposomes [97, 99]. In a study, thymol nanodispersed in WPI-MD conjugates was proven to have superior antimicrobial efficacy against *E. coli* O157:H7, *S.* Typhimurium, *L. monocytogenes*, and *S. aureus* in tryptic soy broth at different pHs and temperatures [98, 99]. Thymol encapsulated in a sodium caseinate nanodispersion demonstrated significantly improved anti-*Listeria* activity in milk with different fat levels, because the nanodispersion can promote better dissolution and distribution compared to thymol crystals [100]. The improved antimicrobial efficacy of the nanodispersed capsules has been evaluated in preliminary experiments against *E. coli* O157:H7, *L. monocytogenes*, *S. aureus* and *S.* Typhimurium in microbiological growth media, apple cider, and 2% reduced-fat milk [97]. Most recently, a thymol nanodispersion has been fortified with lecithin and gelatin to improve stability and efficacy, and the complex was applied to enhance the microbial safety of low-acid foods (pH > 4.6) [101].

In another study, nanodispersed eugenol was found to be effective in inhibiting the growth of *E. coli* O157:H7 and *L. monocytogenes* in milk. The researcher also speculated that nanodispersed eugenol can be easily and evenly distributed in liquid matrices at concentrations above the conventional solubility limit, and supplied the antimicrobial locally when the binding resulted in a eugenol level below the inhibition requirement [102]. A carvacrol-chitosan nanoemulsion was reported to improve the interaction between the nanoparticles and the bacterial membrane due to electrostatic attraction, which led to improved inactivation of *E. coli* O157:H7 in cut romaine lettuce [103].

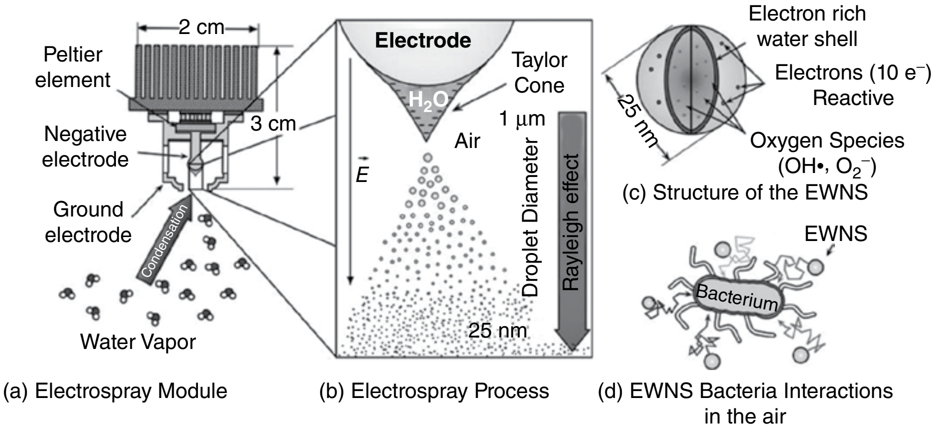
Although nanodispersion technology has been identified as a promising strategy for essential oils, it is important to consider the sensory attributes associated with these aromatic and volatile antimicrobial compounds in real-world food products. Further investigations may also include the effect of lipid content on the structural stability of nanodispersed capsules and the antimicrobial efficacy of encapsulated essential oils in food systems. This cost-effective and scalable technology is expected to result in more applications for other lipophilic food ingredients.

Multifunctional Nanofibers with Biological Control Agents. Lytic bacteriophages have emerged as a novel biocontrol intervention to specifically limit the growth of pathogenic microorganisms in minimally processed foods [104, 105]. Bacteriophage, which are of nanometer scale are natural viruses that specifically target selected strains of bacteria. Bacteriophage are highly bactericidal because they can rapidly multiply in the bacterial cytoplasm to 100–10,000 units in 30~40 minutes, which leads to the lysis of infected bacterial cells [106].

The ability to preserve and deliver bacteriophage in liquid and solid food matrices remains a challenge requiring further investigation; however, some strategies have been explored [107, 108]. One study demonstrated that electrically spun nanofibers from functionalized polyacrylonitrile (PAN) can retain over 99.99% of bacterial cells and phage viruses in water [107]. Another study investigated the preservation of bacteriophage T7 in electrically spun polyvinylpyrrolidone nanofiber. The addition of magnesium salts can increase the conductivity of the stock solution, and protect the infectivity of the bacteriophage during the high voltage electrospinning process [108].

Bacteriophage have also been investigated as biocontrol agents in antimicrobial coating materials. WPI films have been used to encapsulate and stabilize phage infectivity over a period of one month at ambient and refrigerated conditions [109]. Additionally, the WPI films can rapidly release a significant amount of phage to an aqueous environment with as short as 6 hours of incubation. An WPI film embedded with bacteriophage has been reported as an effective intervention material against *E. coli* [109].

Engineered Water Nanostructures. Current sanitization practices in the fresh produce industry rely heavily on washing with antimicrobial chemicals, especially chlorine. A new technology using engineered water nanostructures (EWNS) has been explored as a substituent of the chlorine-based sanitizing method. EWNS are generated by electrospraying of water vapor through a needle electrode (Figure 36.11). EWNS carry unique physicochemical and biological properties, especially reactive oxygen species (ROS) encapsulated in nanoscale water shells enriched by electrons that stabilize water nanoparticles by electrostatic repulsion [110]. The EWNS properties can be precisely controlled, including the nanoparticle diameter, the concentration of ROS, and the



(a) Electrospray Module (b) Electrospray Process (c) Structure of the EWNS (d) EWNS Bacteria Interactions in the air

Figure 36.11 Schematic view of engineered water nanostructures: (a) electrospray module; (b) generation of EWNS; (c) EWNS nanostructures; (d) bactericidal property of EWNS [110].

surface electron charge density. EWNS can be applied to inactivate microorganisms in air and on produce surfaces, as well as on food contact surfaces. The major advantage of this intervention technology is that it does not utilize chemicals, and has no chemical residues or hazardous byproducts in the final product or released into the environment, and thus it improves the food safety of fresh and minimally processed produce in a sustainable way.

EWNS have been found to have the capability to inactivate airborne mycobacteria, which are considered to be the most resilient microbial forms due to their unique cellular structures and slow growth rate. The study also found that EWNS can reduce the airborne microbial concentration significantly, and can also achieve surface disinfection eight times faster than conventional methods, including chlorine, ozone, and so on [110]. In another study, EWNS were employed as a sanitization method for food and contact surfaces. The study found that EWNS have high antimicrobial efficacy against *E. coli*, *S. enterica*, and *L. innocua* on tomato and stainless steel surfaces. Two different exposure approaches have been developed: (i) delivery of EWNS by diffusion; (ii) electrostatic precipitator exposure system (EPES) [111]. At an EWNS concentration of 24,000 counts/cm^3, both delivery approaches can reduce the bacterial counts on stainless steel surfaces by 0.7–1.8 log/cm^2. The EPES approach can achieve 1.4 log/cm^2 reduction of *E. coli* on organic tomato surfaces with 50,000 counts/cm^3 of aerosol concentration and 90 minutes of exposure time [111]. A more recent study has shown that the surface charge of EWNS particles can be quadrupled and the ROS content increased. Pathogenic microbial inactivation rates were improved up to 3.8 logs after 45 mins of exposure to an EWNS aerosol dose of 40,000 counts/cm^3 [112]. Although more work is needed to characterize the impact of oxygen species on produce quality, the results indicate that this novel, chemical-free, and green intervention approach possesses potential for the fresh produce industry [111].

36.2.2.2 Surface Treatment and Nanoscale Coating

Food contact surfaces, such as worktables, processing equipment, conveyor belts, transport baskets, packaging, processing tools, and so on, represent a major concern for pathogen cross-contamination during food processing [113]. Given that these surfaces are often sanitized on a shift basis, a clean surface can be easily contaminated and immediately become a source of cross-contamination throughout the remaining process [114, 115]. Significant progress in nanotechnology has offered a number of new intervention technologies in these areas, through the development of antimicrobial coatings, nanocomposites, and physical topographical modification.

Antimicrobial Coatings and Surface Treatments. A group of antimicrobial agents and fabrication technologies have been exploited for antimicrobial coatings on food contact surfaces. The type of antimicrobial coating, however, is dependent on the physical parameters of the surface, as well as the chemical properties of the material. For instance, materials may only be applicable for certain surface shapes and sizes, or may have chemical limitations, given the nature of the antimicrobial and the type of surface used. The application process must also be considered due to variability in specific attributes, such as the cost, the effectiveness of antimicrobial activity, and consistency of coatings. Stainless steel materials are most widely adopted in the food industrial environment, because the material is nonreactive. Therefore, modification of the stainless steel surface with functional groups is required to ensure adherence of the coating to it. Figure 36.12 illustrates several coating methods for antimicrobial surface adhesion. In addition to antimicrobial efficacy, the antimicrobial selection is multifactorial, including the bactericidal mechanism, reusability, and stability against pH, temperature, and sanitization regimens [116].

Surface chemical modification with antimicrobials has been exploited as an alternative and easy-to-apply treatment method. N-halamines, compounds that contain one or more covalent nitrogen–halogen bonds, have drawn increasing attention as a result

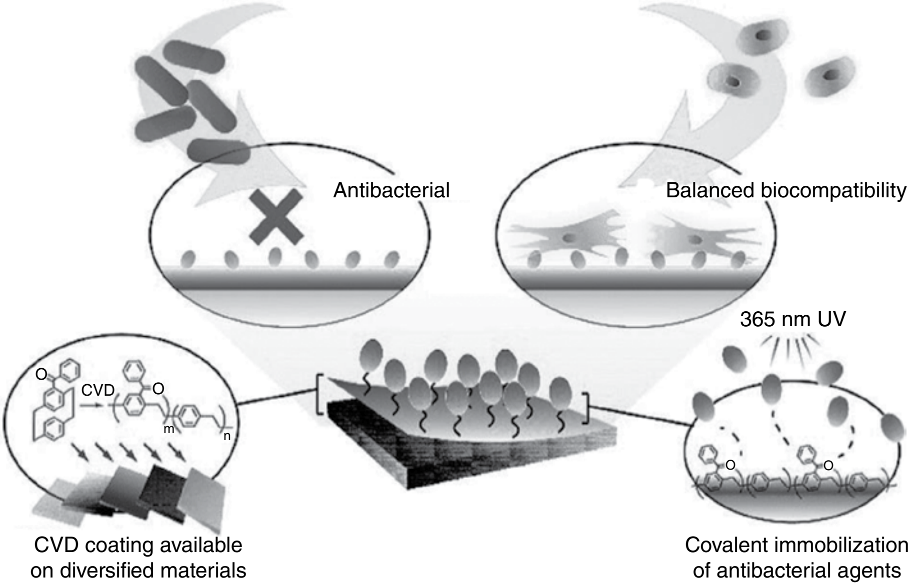


Figure 36.12 Schematic of coating technologies via compatibility balanced antibacterial modification [116].

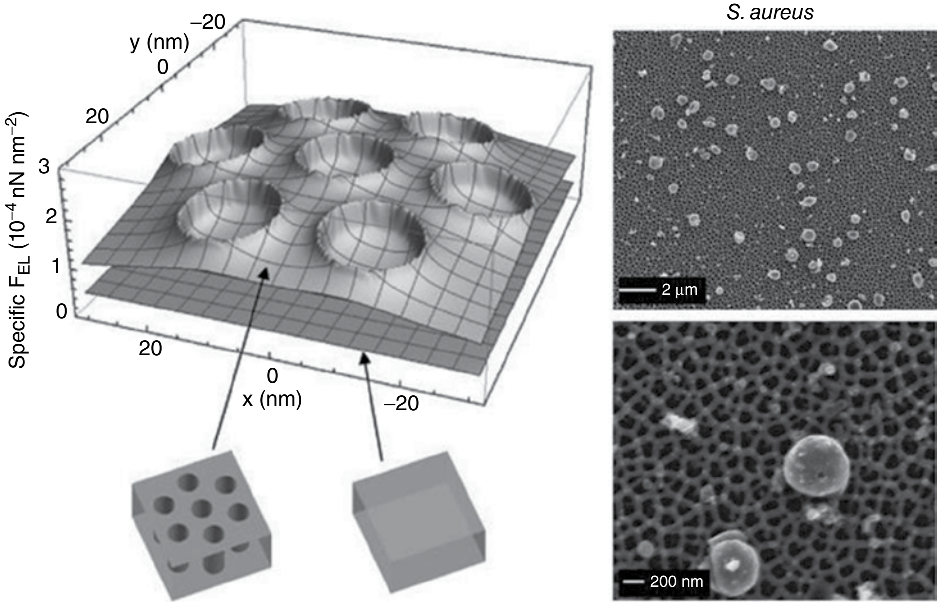


Figure 36.13 Illustration of the spatial distribution of the repulsive electrostatic field against *E. coli* O157:H7 cells on an anodic alumina surface with packed nanopores of 15 nm (left). Scanning electron micrographs of *S. aureus* after 48 h of contact with anodic alumina surfaces with packed 100 nm nanopores [122].

of their strong antimicrobial properties [117, 118]. Multiple formation and modification strategies of the food contact surfaces have been developed on stainless steel and polyethylene via simple layer-by-layer deposition of polyelectrolyte [117, 119]. The N-halamine-modified surfaces showed promising bactericidal results with > 5 log reduction of food-borne pathogens, including *Listeria* [117].

Recent studies found that surface roughness at the nanoscale can prevent the attachment and proliferation of pathogenic bacteria (Figure 36.13) [120–122]. The most effective antifouling was found on an alumina-based material with engineered nanopores with diameters of 15 nm and 25 nm [122]. This phenomenon was attributed to the enhanced repulsion of electrostatic forces between the engineered surface and bacterial cells [120–122]. These findings indicate that the physical properties of a food contact material can be tailored to prevent the attachment of bacteria and the formation of biofilms.

Nanocomposite Polymers. Recently, metallic or silicon-based nanomaterials have been incorporated into packaging polymeric materials to improve mechanical and gas barrier properties and the durability of plastic materials. Additionally, metallic materials that are effective antimicrobials can also be incorporated into food packaging materials for food preservation purposes.

Silver nanocolloids are one of the most exploited commodities due to their broad-spectrum and high antimicrobial activities [123, 124]. Several studies have demonstrated the feasibility of applying silver-based coatings on food-contact equipment or packaging surfaces to prevent the formation of biofilms [125]. Food contact surfaces may include cutting boards, display cases, refrigerators, food processing equipment, and reusable food packaging. Copper, zinc, and titanium nanostructures have all shown promise for future food safety applications. Copper-based nanomaterials have been developed as indicators of humidity, which is a critical factor supporting microbial growth [126]. Zinc oxide nanoparticles have been developed as a cost-effective and safe intervention strategy compared to silver nanocolloids. Titanium oxide embedded in food contact materials has also been shown to have effective antimicrobial activities [127–129]. The advancement of novel nanocomposites is providing better functionalities for tailored applications on food-contact surfaces and in active food packaging materials. However, prior to implementation, a proper risk assessment of these applications is necessary to ensure the safe use of metallic nanoparticles [127].

36.3 Current Efforts and Future Directions

The nanotechnology applications presented in this chapter exhibit promise for future prospects in improving food safety. Nanotechnology-enabled biosensors are capable of higher sensitivity and specificity, are faster than traditional methods, and are more versatile and robust. Future research should focus on translational efforts to move the promising bench-top discoveries and prototypes into practical industrial applications. In order to further advance detection of food-borne pathogens and toxins, system integration should deliver sensitive, specific, accurate, rapid, real-time, and easy to use devices for analyzing real food samples in the production field, processing plant, food service establishment, distribution and retailers, and even for consumer use. The new systems should outperform the current RNA-based technologies in terms of speed and accuracy. The ideal sensitivity should aim at 1 CFU/25 g to 1 CFU/375 g, with the ability to distinguish the target microorganisms among large numbers of competitive microbes. More advanced sampling methods and innovative pretreatments may be helpful.

Future research should also develop more effective and affordable preventive controls and innovative pathogen inactivation treatments. For food pathogen preventive measures, the new technologies should be effective and practical. Alternatives to antibiotic uses in treating animal diseases and pathogens should be investigated. Pathogen inactivation technologies are needed that can inactivate greater than 5 log CFUs of target pathogen(s), within a time frame comparable to the current industry processes. The new nanotechnology-enabled treatments should have no apparent adverse effects on nutrient retention and organoleptic characteristics (odor, color, texture, flavor, overall appearance). Antimicrobial treatment delivery systems that leave minimal or no undesirable chemical residues should be sought.

Environmental, health, and safety implications of nanoparticles have been an integral part of research and development of nanotechnology applications. The implications of food nanotechnology focus on understanding the physical, chemical, and biological properties of engineered nanoparticles with regard to risk and exposure to the environment and human health. More research is needed to investigate the transportation, migration, and accumulation of engineered nanomaterials in the environment.

Lack of familiarity with nanotechnology and overstatement of the risks by its opponents have created deep-seated feelings of fear and distrust among the general public.

Over time, information provided on the benefits of nanotechnology applications has shifted public perception slightly in a favorable direction [130]. However, more efforts are needed to improve public understanding of the benefits and risks of nanotechnologies in food and agricultural applications. Broader public engagement will be helpful in guiding the course of nanotechnology R&D in the future.

References

1 Centers for Disease Control and Prevention (CDC). Surveillance for foodborne disease outbreaks, United States. Atlanta, GA: US Department of Health and Human Services, CDC; 2014.
2 Marino D. Water and food safety in the developing world: global implications for health and nutrition of infants and young children. *Journal of the Academy of Nutrition and Dietetics.* 2007;11:1930–4.
3 Chen H, Yada R. Nanotechnologies in agriculture: new tools for sustainable development. *Trends in Food Science and Technology.* 2011;22(11):585–94.
4 Chen H, Seiber JN, Hotze M. ACS select on nanotechnology in food and agriculture: a perspective on implications and applications. *Journal of Agricultural and Food Chemistry.* 2014;62(6):1209–12.
5 Lam H, Remais J, Fung M, *et al.* Food supply and food safety issues in China. *The Lancet.* 2013;381(9882):2044–53.
6 Roco M. The long view of nanotechnology development: the national nanotechnology initiative at 10 years. *Journal of Nanoparticle Research.* 2011;13:427–45.
7 Konduru T, Parimi N, Rains G, Ramasamy R. Electrochemical sensor for detection of volatiles released by plants. *Proceedings of the 220th The Electrochemical Society Meeting.* 2011:2491.
8 Umasankar Y, Rains GC, Ramasamy RP. Electroanalytical studies on green leaf volatiles for potential sensor development. *Analyst.* 2012;137(13):3138–45.
9 Luo X, Wu H-C, Tsao C-Y, Cheng Y, Betz J, Payne GF, et al. Biofabrication of stratified biofilm mimics for observation and control of bacterial signaling. *Biomaterials.* 2012;33(20):5136–43.
10 Zhou M, Dong S. Bioelectrochemical interface engineering: toward the fabrication of electrochemical biosensors, biofuel cells, and self-powered logic biosensors. *Accounts of Chemical Research.* 2011;44(11):1232–43.
11 Bitinis N, Hernandez M, Verdejo R, Kenny JM, Lopez-Manchado MA. Recent advances in clay/polymer nanocomposites. *Advanced Materials.* 2011;23(44):5229–36.
12 Fu Y, Zou C, Bu L, Xie Q, Yao S. Novel amperometric aptasensor based on analyte-induced suppression of enzyme catalysis in polymeric bionanocomposites. *ACS Applied Materials and Interfaces.* 2013;5(3):934–9.
13 Zang S, Liu Y, Lin M, Kang J, Sun Y, Lei H. A dual amplified electrochemical immunosensor for ofloxacin: Polypyrrole film-Au nanocluster as the matrix and multi-enzyme-antibody functionalized gold nanorod as the label. *Electrochimica Acta.* 2013;90:246–53.
14 Pei H, Li J, Lv M, Wang J, Gao J, Lu J, et al. A graphene-based sensor array for high-precision and adaptive target identification with ensemble aptamers. *Journal of the American Chemical Society.* 2012;134(33):13843–9.

15 Fan Z, Lin Q, Gong P, Liu B, Wang J, Yang S. A new enzymatic immobilization carrier based on graphene capsule for hydrogen peroxide biosensors. *Electrochimica Acta.* 2015;151:186–94.

16 Qiu J-D, Zhou W-M, Guo J, Wang R, Liang R-P. Amperometric sensor based on ferrocene-modified multiwalled carbon nanotube nanocomposites as electron mediator for the determination of glucose. *Analytical Biochemistry*. 2009;385(2):264–9.

17 Wang X-F, Zhou Y, Xu J-J, Chen H-Y. Signal-on electrochemiluminescence biosensors based on CdS-barbon nanotube nanocomposite for the sensitive detection of choline and acetylcholine. *Advanced Functional Materials*. 2009;19(9):1444–50.

18 Ramanavicius A, Ramanaviciene A, Malinauskas A. Electrochemical sensors based on conducting polymer-polypyrrole. *Electrochimica Acta*. 2006;51(27):6025–37.

19 Thomas D. *Advanced Biomaterials for Medical Applications*. Netherlands: Kluwer Academic Publishers; 2004.

20 Zhuo Y, Yuan P-X, Yuan R, Chai Y-Q, Hong C-L. Bienzyme functionalized three-layer composite magnetic nanoparticles for electrochemical immunosensors. *Biomaterials.* 2009;30(12):2284–90.

21 Kumar S, Ahlawat W, Kumar R, Dilbaghi N. Graphene, carbon nanotubes, zinc oxide and gold as elite nanomaterials for fabrication of biosensors for healthcare. *Biosensors and Bioelectronics.* 2015;70:498–503.

22 Zheng B, Cheng S, Liu W, Lam MH-W, Liang H. Small organic molecules detection based on aptamer-modified gold nanoparticles-enhanced quartz crystal microbalance with dissipation biosensor. *Analytical Biochemistry.* 2013;438(2):144–9.

23 Zeng Q, Cheng J, Tang L, Liu X, Liu Y, Li J, et al. Self-assembled graphene-enzyme hierarchical nanostructures for electrochemical biosensing. *Advanced Functional Materials*. 2010;20(19):3366–72.

24 Ping J, Wang Y, Fan K, Wu J, Ying Y. Direct electrochemical reduction of graphene oxide on ionic liquid doped screen-printed electrode and its electrochemical biosensing application. *Biosensors and Bioelectronics*. 2011;28(1):204–9.

25 Tang W, Wu J, Ying Y, Liu Y. Writing sensors on solid agricultural products for in situ detection. *Analytical Chemistry*. 2015;87(21):10703–7.

26 Hirsch A. Functionalization of single-walled carbon nanotubes. *Angewandte Chemie-International Edition*. 2002;41(11):1853–9.

27 Grieshaber D, MacKenzie R, Voeroes J, Reimhult E. Electrochemical biosensors - Sensor principles and architectures. *Sensors*. 2008;8(3):1400–58.

28 Jiang X, Li D, Xu X, *et al.* Immunosensors for detection of pesticide residues. *Biosensors and Bioelectronics*. 2008;23(11):1577–87.

29 Jiang X, Wang R, Wang Y, *et al.* Evaluation of different micro/nanobeads used as amplifiers in QCM immunosensor for more sensitive detection of *E. coli* O157:H7. *Biosensors and Bioelectronics*. 2011;29(1):23–8.

30 Wang J. Electrochemical glucose biosensors. *Chemical Reviews*. 2008;108(2):814–25.

31 Liu J, Cao Z, Lu Y. Functional nucleic acid sensors. *Chemical Reviews*. 2009;109(5):1948–98.

32 Arechederra RL, Minteer SD. Self-powered sensors. *Analytical and Bioanalytical Chemistry*. 2011;400(6):1605–11.

33 Zhang F, Wu J, Wang R, Wang L, Ying Y. Portable pH-inspired electrochemical detection of DNA amplification. *Chemical Communications*. 2014;50(61):8416–9.

34 Liu Y, Dong S. A biofuel cell harvesting energy from glucose-air and fruit juice-air. *Biosensors and Bioelectronics*. 2007;23(4):593–7.

35 Zloczewska A, Celebanska A, Szot K, Tomaszewska D, Opallo M, Joensson-Niedziolka M. Self-powered biosensor for ascorbic acid with a Prussian blue electrochromic display. *Biosensors and Bioelectronics.* 2014;54:455–61.

36 Sekretaryova AN, Beni V, Eriksson M, Karyakin AA, Turner APF, Vagin MY. Cholesterol self-powered biosensor. *Analytical Chemistry*. 2014;86(19):9540–7.

37 Zhao Y, Deng P, Nie Y, Wang P, Zhang Y, Xing L, et al. Biomolecule-adsorption-dependent piezoelectric output of ZnO nanowire nanogenerator and its application as self-powered active biosensor. *Biosensors and Bioelectronics.* 2014;57:269–75.

38 Wong LP, Wei Y, Toh C-S. Self-powering amperometric sensor and biosensor. *Journal of Electroanalytical Chemistry.* 2012;671:80–4.

39 Liu B, Lei Y, Li B. A batch-mode cube microbial fuel cell based "shock" biosensor for wastewater quality monitoring. *Biosensors and Bioelectronics.* 2014;62:308–14.

40 Rasmussen M, Minteer SD. Long-term arsenic monitoring with an Enterobacter cloacae microbial fuel cell. *Bioelectrochemistry.* 2015;106:207–12.

41 Liang J, Xu J, Pan J, Ge M, Zong K. Identification of the main allergenic proteins in high hydrostatic pressure pineapple juice and assessing the influence of pressure on their allergenicity. *International Journal of Food Properties*. 2015;18(10):2134–44.

42 Chakraborty S, Baier D, Knorr D, Mishra HN. High pressure inactivation of polygalacturonase, pectinmethylesterase and polyphenoloxidase in strawberry puree mixed with sugar. *Food and Bioproducts Processing.* 2015;95:281–91.

43 Tomlin BD, Jones SE, Reyes-De-Corcuera JI. High hydrostatic pressure protection of a pectinase cocktail against thermal inactivation. *Journal of Food Engineering.* 2013;116(3):674–80.

44 Ardhaoui M, Bhatt S, Zheng M, Dowling D, Jolivalt C, Khonsari FA. Biosensor based on laccase immobilized on plasma polymerized allylamine/carbon electrode. *Materials Science and Engineering C – Materials for Biological Applications.* 2013;33(6):3197–205.

45 Eisenmenger MJ, Reyes-De-Corcuera JI. High hydrostatic pressure increased stability and activity of immobilized lipase in hexane. *Enzyme and Microbial Technology.* 2009;45(2):118–25.

46 Feng P. Detecting foodborne pathogens and their toxins: Conventional versus rapid and automated methods. In: Doyle M, Beuchat L, editors, *Food Microbiology: Fundamentals and Frontiers*. 3rd edn. Washington, D.C.: ASM Press; 2007.

47 Jasson V, Jacxsens L, Luning P, Rajkovic A, Uyttendaele M. Alternative microbial methods: an overview and selection criteria. *Food Microbiology*. 2010;27(6):710–30.

48 López-Campos G, Martínez-Suárez J-V, Aguado-Urda M, López-Alonso, V. *Microarray Detection and Characterization of Bacterial Foodborne Pathogens*. New York, NY: Springer, US; 2012.

49 Wang Y, Ye Z, Ping J, Jing S, Ying Y. Development of an aptamer-based impedimetric bioassay using microfluidic system and magnetic separation for protein detection. *Biosensors and Bioelectronics.* 2014;59:106–11.

50 Li Y, Liu Y, Gao T, Zhang B, Song Y, Terrell JL, et al. Self-assembly with orthogonal-imposed stimuli to impart structure and confer magnetic function to electrodeposited hydrogels. *ACS Applied Materials and Interfaces*. 2015;7(19):10587–98.

51 Luo X, Lewandowski AT, Yi H, Payne GF, Ghodssi R, Bentley WE, et al. Programmable assembly of a metabolic pathway enzyme in a pre-packaged reusable bioMEMS device. *Lab on a Chip*. 2008;8(3):420–30.

52 Kim E, Liu Y, Bentley WE, Payne GF. Redox capacitor to establish bio-device redox-connectivity. *Advanced Functional Materials*. 2012;22(7):1409–16.

53 Tsao C-Y, Hooshangi S, Wu H-C, Valdes JJ, Bentley WE. Autonomous induction of recombinant proteins by minimally rewiring native quorum sensing regulon of *E. coli*. *Metabolic Engineering*. 2010;12(3):291–7.

54 Kim E, Liu Y, Shi X-W, Yang X, Bentley WE, Payne GF. Biomimetic approach to confer redox activity to thin chitosan films. *Advanced Functional Materials*. 2010;20(16):2683–94.

55 Kim E, Xiong Y, Cheng Y, Wu H-C, Liu Y, Morrow B, et al. Chitosan to connect biology to electronics: fabricating the bio-device interface and communicating across this interface. *Polymers*. 2015;7(1):1–46.

56 Zheng J, He L. Surface-enhanced Raman spectroscopy for the chemical analysis of food. *Comprehensive Reviews in Food Science and Food Safety*. 2014;13(3):317–28.

57 Bergwerff A, Van Knapen F. Surface plasmon resonance biosensors for detection of pathogenic microorganisms: strategies to secure food and environmental safety. *Journal of AOAC International*. 2006;89(3):826–31.

58 Peng S, Derrien TL, Cui J, Xu C, Luo D. From cells to DNA materials. *Materials Today*. 2012;15(5):190–4.

59 Song C, Min L, Zhou N, Yang Y, Yang B, Zhang L, et al. Ultrasensitive detection of carcino-embryonic antigen by using novel flower-like gold nanoparticle SERS tags and SERS-active magnetic nanoparticles. *RSC Advances*. 2014;4(78):41666–9.

60 Lombardi J, Birke R. A unified approach to surface-enhanced Raman spectroscopy. *Journal of Physical Chemistry C*. 2008;112(14):5605–17.

61 Zhang X-F, Zou M-Q, Qi X-H, Liu F, Zhu X-H, Zhao B-H. Detection of melamine in liquid milk using surface-enhanced Raman scattering spectroscopy. *Journal of Raman Spectroscopy*. 2010;41(12):1655–60.

62 Xu X, Liu X, Li Y, Ying Y. A simple and rapid optical biosensor for detection of aflatoxin B1 based on competitive dispersion of gold nanorods. *Biosensors and Bioelectronics*. 2013;47:361–7.

63 Liu X, Tang L, Niessner R, Ying Y, Haisch C. Nitrite-triggered surface plasmon-assisted catalytic conversion of p-aminothiophenol to p,p’-dimercaptoazobenzene on gold nanoparticle: surface-enhanced Raman scattering investigation and potential for nitrite detection. *Analytical Chemistry*. 2015;87(1):499–506.

64 Galarreta BC, Tabatabaei M, Guieu V, Peyrin E, Lagugne-Labarthet F. Microfluidic channel with embedded SERS 2D platform for the aptamer detection of ochratoxin A. *Analytical and Bioanalytical Chemistry*. 2013;405(5):1613–21.

65 Huai Q-y, Gao C-l, Miao J-l, Yao H-l, Wang Z-l. Fast detection of saxitoxin using laser tweezers surface enhanced Raman spectroscopy. *Analytical Methods*. 2013;5(23):6870–3.

66 Lin W-C, Jen H-C, Chen C-L, Hwang D-F, Chang R, Hwang J-S, et al. SERS study of tetrodotoxin (TTX) by using silver nanoparticle arrays. *Plasmonics*. 2009;4(2):187–92.

67 Zhu Y, Kuang H, Xu L, Ma W, Peng C, Hua Y, et al. Gold nanorod assembly based approach to toxin detection by SERS. *Journal of Materials Chemistry*. 2012;22(6):2387–91.

68 Jiang X, Jiang Z, Xu T, Su S, Zhong Y, Peng F, et al. Surface-enhanced Raman scattering-based sensing in vitro: facile and label-free detection of apoptotic cells at the single-cell level. *Analytical Chemistry*. 2013;85(5):2809–16.

69 Madeira A, Ohman E, Nilsson A, Sjogren B, Andren PE, Svenningsson P. Coupling surface plasmon resonance to mass spectrometry to discover novel protein-protein interactions. *Nature Protocols*. 2009;4(7):1023–37.

70 Narsaiah K, Jha SN, Bhardwaj R, Sharma R, Kumar R. Optical biosensors for food quality and safety assurance-a review. *Journal of Food Science and Technology-Mysore*. 2012;49(4):383–406.

71 Bergwerff AA, Van Knapen F. Surface plasmon resonance biosensors for detection of pathogenic microorganisms: strategies to secure food and environmental safety. *Journal of AOAC International*. 2006;89(3):826–31.

72 Dudak FC, Boyaci IH. Development of an immunosensor based on surface plasmon resonance for enumeration of Escherichia coli in water samples. *Food Research International*. 2007;40(7):803–7.

73 Situ C, Buijs J, Mooney MH, Elliott CT. Advances in surface plasmon resonance biosensor technology towards high-throughput, food-safety analysis. *TrAC – Trends in Analytical Chemistry*. 2010;29(11):1305–15.

74 Trabucchi A, Guerra LL, Faccinetti NI, Iacono RF, Poskus E, Valdez SN. Surface plasmon resonance reveals a different pattern of proinsulin autoantibodies concentration and affinity in diabetic patients. *Plos One*. 2012;7(3): e33574.

75 Sleightholm L, Zambre A, Chanda N, Afrasiabi Z, Katti K, Kannan R. New nanomedicine approaches using gold-thioguanine nanoconjugates as metallo-ligands. *Inorganica Chimica Acta*. 2011;372(1):333-9.

76 Zambre A, Silva F, Upendran A, Afrasiabi Z, Xin Y, Paulo A, et al. Synthesis and characterization of functional multicomponent nanosized gallium chelated gold crystals. *Chemical Communications*. 2014;50(25):3281–4.

77 Zambre A, Chanda N, Prayaga S, Almudhafar R, Afrasiabi Z, Upendran A, et al. Design and development of a field applicable gold nanosensor for the detection of luteinizing hormone. *Analytical Chemistry*. 2012;84(21):9478–84.

78 Lin M, Wang J, Zhou G, Wang J, Wu N, Lu J, et al. Programmable engineering of a biosensing interface with tetrahedral DNA nanostructures for ultrasensitive DNA detection. *Angewandte Chemie International Edition*. 2015;54(7):2151–5.

79 Yan J, Hu C, Wang P, Zhao B, Ouyang X, Zhou J, et al. Growth and origami folding of DNA on nanoparticles for high-efficiency molecular transport in cellular imaging and drug delivery. *Angewandte Chemie International Edition*. 2015;54(8):2431–5.

80 Li YG, Tseng YD, Kwon SY, D'Espaux L, Bunch JS, McEuen PL, et al. Controlled assembly of dendrimer-like DNA. *Nature Materials*. 2004;3(1):38–42.

81 Um SH, Lee JB, Kwon SY, Li Y, Luo D. Dendrimer-like DNA-based fluorescence nanobarcodes. *Nature Protocols*. 2006;1(2):995–1000.

82 Li Y, Cu Y, Luo D. Multiplexed detection of pathogen DNA with DNA-based fluorescence nanobarcodes. *Nature Biotechnology*. 2005;23(7):885–9.

83 Um SH, Lee JB, Park N, Kwon SY, Umbach CC, Luo D. Enzyme-catalysed assembly of DNA hydrogel. *Nature Materials*. 2006;5(10):797–801.

84 Lee JB, Roh YH, Um SH, Funabashi H, Cheng W, Cha JJ, et al. Multifunctional nanoarchitectures from DNA-based ABC monomers. *Nature Nanotechnology*. 2009;4(7):430–6.

85 Lee J, Roh Y, Um S-H, Funabashi H, Cheng W, Cha J, et al. Multifunctional nanoarchitectures from DNA-based ABC monomers. *Nature Nanotechnology*. 2009;4(7):430–6.

86 Kim H, Park Y, Kim J, Jeong J, Han S, Lee J-S, et al. Nucleic acid engineering: RNA following the trail of DNA. *ACS Combinatorial Science*. 2016;18(2):87–99.

87 Lee JB, Peng S, Yang D, Roh YH, Funabashi H, Park N, et al. A mechanical metamaterial made from a DNA hydrogel. *Nature Nanotechnology*. 2012;7(12):816–20.

88 Pei H, Li F, Wan Y, Wei M, Liu H, Su Y, et al. Designed diblock oligonucleotide for the synthesis of spatially isolated and highly hybridizable functionalization of DNA-gold nanoparticle nanoconjugates. *Journal of the American Chemical Society*. 2012;134(29):11876–9.

89 Pei H, Zuo X, Zhu D, Huang Q, Fan C. Functional DNA nanostructures for theranostic applications. *Accounts of Chemical Research*. 2014;47(2):550–9.

90 Chang Y, McLandsborough L, McClements DJ. Antimicrobial delivery systems based on electrostatic complexes of cationic epsilon-polylysine and anionic gum arabic. *Food Hydrocolloids*. 2014;35:137–43.

91 Chang Y, McClements DJ. Optimization of orange oil nanoemulsion formation by isothermal low-energy methods: influence of the oil phase, surfactant, and temperature. *Journal of Agricultural and Food Chemistry*. 2014;62(10):2306–12.

92 Lopez-Pena CL, Zheng B, Sela DA, Decker EA, Xiao H, McClements DJ. Impact of epsilon-polylysine and pectin on the potential gastrointestinal fate of emulsified lipids: In vitro mouth, stomach and small intestine model. *Food Chemistry*. 2016;192:857–64.

93 Loeffler M, McClements DJ, McLandsborough L, Terjung N, Chang Y, Weiss J. Electrostatic interactions of cationic lauric arginate with anionic polysaccharides affect antimicrobial activity against spoilage yeasts. *Journal of Applied Microbiology*. 2014;117(1):28–39.

94 Asker D, Weiss J, McClements DJ. Formation and stabilization of antimicrobial delivery systems based on electrostatic complexes of cationic-non-ionic mixed micelles and anionic polysaccharides. *Journal of Agricultural and Food Chemistry*. 2011;59(3):1041–9.

95 Weiss J, Gaysinsky S, Davidson M, McClements J. Nanostructured encapsulation systems: food antimicrobials. In: Barbosa-Cánovas G, Mortimer A, Lineback D, Spiess W, Buckle K, Colonna P, editors, *Global Issues in Food Science and Technology*. Oxford, UK: Elsevier Inc.; 2009.

96 Gutierrez J, Barry-Ryan C, Bourke R. The antimicrobial efficacy of plant essential oil combinations and interactions with food ingredients. *International Journal of Food Microbiology*. 2008;124(1):91–7.

97 Shah B, Davidson PM, Zhong Q. Nanocapsular dispersion of thymol for enhanced dispersibility and increased antimicrobial effectiveness against *Escherichia coli* O157:H7 and Listeria monocytogenes in model food systems. *Applied and Environmental Microbiology*. 2012;78(23):8448–53.

98 Shah B, Davidson PM, Zhong Q. Antimicrobial activity of nanodispersed thymol in tryptic soy broth. *Journal of Food Protection*. 2013;76(3):440–7.

99 Shah B, Ikeda S, Davidson PM, Zhong Q. Nanodispersing thymol in whey protein isolate-maltodextrin conjugate capsules produced using the emulsion-evaporation technique. *Journal of Food Engineering*. 2012;113(1):79–86.

100 Pan K, Chen H, Davidson PM, Zhong Q. Thymol nanoencapsulated by sodium caseinate: physical and antilisterial properties. *Journal of Agricultural and Food Chemistry*. 2014;62(7):1649–57.

101 Xue J, Zhong Q. Blending lecithin and gelatin improves the formation of thymol nanodispersions. *Journal of Agricultural and Food Chemistry*. 2014;62(13):2956–62.

102 Shah B, Davidson PM, Zhong Q. Nanodispersed eugenol has improved antimicrobial activity against *Escherichia coli* O157:H7 and *Listeria monocytogenes* in bovine milk. *International Journal of Food Microbiology*. 2013;161(1):53–9.

103 Vasquez Mejia CM. *Effect of carvacrol-loaded nanoemulsions on a bioluminescent strain of Escherichia coli O157:H7*. ProQuest Dissertations Publishing: Purdue University; 2014.

104 Hagens S, Loessner MJ. Application of bacteriophages for detection and control of foodborne pathogens. *Applied Microbiology and Biotechnology*. 2007;76(3):513–9.

105 Luo Z, Simmons CW, VanderGheynst JS, Nitin N. Quantitative real time measurements of bacteria-bacteriophages interactions in fresh lettuce leaves. *Journal of Food Engineering*. 2012;111(1):176–85.

106 Abuladze T, Li M, Menetrez MY, Dean T, Senecal A, Sulakvelidze A. Bacteriophages reduce experimental contamination of hard surfaces, tomato, spinach, broccoli, and ground beef by *Escherichia coli* O157 : H7. *Applied and Environmental Microbiology*. 2008;74(20):6230–8.

107 Ma H, Hsiao BS, Chu B. Functionalized electrospun nanofibrous microfiltration membranes for removal of bacteria and viruses. *Journal of Membrane Science*. 2014;452:446–52.

108 Dai M, Senecal A, Nugen SR. Electrospun water-soluble polymer nanofibers for the dehydration and storage of sensitive reagents. *Nanotechnology*. 2014;25(22): 225101.

109 Vonasek E, Phuong L, Nitin N. Encapsulation of bacteriophages in whey protein films for extended storage and release. *Food Hydrocolloids*. 2014;37:7–13.

110 Pyrgiotakis G, McDevitt J, Gao Y, Branco A, Eleftheriadou M, Lemos B, et al. Mycobacteria inactivation using engineered water nanostructures (EWNS). *Nanomedicine – Nanotechnology Biology and Medicine*. 2014;10(6):1175–83.

111 Pyrgiotakis G, Vasanthakumar A, Gao Y, Eleftheriadou M, Toledo E, DeAraujo A, et al. Inactivation of foodborne microorganisms using engineered water nanostructures (EWNS). *Environmental Science and Technology*. 2015;49(6):3737–45.

112 Pyrgiotakis G, Vedantam P, Cirenza C, McDevitt J, Eleftheriadou M, Leonard S, et al. Optimization of a nanotechnology based antimicrobial platform for food safety applications using Engineered Water Nanostructures (EWNS). *Scientific Reports*. 2016;6: 21073.

113 Rodriguez A, Autio W, McLandsborough L. Effect of biofilm dryness on the transfer of *Listeria monocytogenes* biofilms grown on stainless steel to bologna and hard salami. *Journal of Food Protection*. 2007;11:2460–694.

114 Bastarrachea LJ, Denis-Rohr A, Goddard JM. Antimicrobial food equipment coatings: applications and challenges. *Annual Review of Food Science and Technology*, 2015;6:97–118.

115 Luo Y, Nou X, Millner P, Zhou B, Shen C, Yang Y, et al. A pilot plant scale evaluation of a new process aid for enhancing chlorine efficacy against pathogen survival and cross-contamination during produce wash. *International Journal of Food Microbiology*. 2012;158(2):133–9.

116 Chang C-H, Yeh S-Y, Lee B-H, Hsu C-W, Chen Y-C, Chen C-J, et al. Compatibility balanced antibacterial modification based on vapor-deposited parylene coatings for biomaterials. *Journal of Materials Chemistry B*. 2014;2(48):8496–503.

117 Bastarrachea L, McLandsborough L, Peleg M, Goddard J. Antimicrobial N-halamine modified polyethylene: characterization, biocidal efficacy, regeneration, and stability. *Journal of Food Science.* 2014;79(5):E887–E97.

118 Denis-Rohr A, Bastarrachea L, Goddard J. Antimicrobial efficacy of N-halamine coatings prepared via dip and spray layer-by-layer deposition. *Food and Bioproducts Processing.* 2015;96:12–19.

119 Bastarrachea L, Denis-Rohr A, Goddard J. Antimicrobial food equipment coatings: applications and challenges. *Annual Review of Food Science and Technology,* 2015;6:97–118.

120 Hsu L, Fang J, Borca-Tasciuc D, Worobo R, Moraru C. Effect of micro- and nanoscale topography on the adhesion of bacterial cells to solid surfaces. *Applied and Environmental Microbiology.* 2013;79(8):2703–12.

121 Feng G, Cheng Y, Wang S-Y, Hsu L, Feliz Y, Borca-Tasciuc D, et al. Alumina surfaces with nanoscale topography reduce attachment and biofilm formation by *Escherichia coli* and *Listeria* spp. *Biofouling.* 2014;30(10):1253–68.

122 Feng G, Cheng Y, Wang S-Y, Borca-Tasciuc D, Worobo R, Moraru C. Bacterial attachment and biofilm formation on surfaces are reduced by smal-diameter nanoscale pores: how small is small enough? *NPJ Biofilms and Microbiomes.* 2015 1:15022.

123 Zhang B, Luo Y, Wang Q. Development of silver-zein composites as a promising antimicrobial agent. *Biomacromolecules.* 2010;11(9):2366–75.

124 Zhang B, Luo Y, Wang Q. Development of silver/alpha-lactalbumin nanocomposites: a new approach to reduce silver toxicity. *International Journal of Antimicrobial Agents.* 2011;38(6):502–9.

125 Griffith A, Neethirajan S, Warriner K. Development and evaluation of silver zeolite antifouling coating on stainless steel for food contact surfaces. *Journal of Food Safety.* 2015;35(3):345–54.

126 Noyce J, Michels H, Keevil C. Use of copper cast alloys to control Escherichia coli O157 cross-contamination during food processing. *Applied Environmental Microbiology* 2006;72(6):4239–44.

127 Llorens A, Lloret E, Picouet PA, Trbojevich R, Fernandez A. Metallic-based micro and nanocomposites in food contact materials and active food packaging. *Trends in Food Science and Technology.* 2012;24(1):19–29.

128 Yemmireddy V, Hung Y-C. Effect of food processing organic matter on photocatalytic bactericidal activity of titanium dioxide (TiO2). *International Journal of Food Microbiology.* 2015;204:75–80.

129 Yemmireddy V, Hung Y-C. Selection of photocatalytic bactericidal titanium dioxide (TiO2) nanoparticles for food safety applications. *LWT – Food Science and Technology.* 2015;61(1):1–6.

130 Besley J. Current research on public perceptions of nanotechnology. *Emerging Health Threats Journal.* 2010;3:e8.

Index

Page numbers in *italics* refer to illustrations; those in **bold** refer to tables

Food Safety in China: Science, Technology, Management and Regulation, First Edition.
Edited by Joseph J. Jen and Junshi Chen.