SPRINGER BRIEFS IN MOLECULAR SCIENCE
CHEMISTRY OF FOODS

Giovanni Gurnari

Safety Protocols in the Food Industry and Emerging Concerns

Springer

SpringerBriefs in Molecular Science

Chemistry of Foods

Series editor

Salvatore Parisi, Industrial Consultant, Palermo, Italy

More information about this series at http://www.springer.com/series/11853

Giovanni Gurnari

Safety Protocols in the Food Industry and Emerging Concerns

Springer

Giovanni Gurnari
Benaquam S.r.l.
San Marino
Italy

ISSN 2191-5407 ISSN 2191-5415 (electronic)
SpringerBriefs in Molecular Science
ISSN 2199-689X ISSN 2199-7209 (electronic)
Chemistry of Foods
ISBN 978-3-319-16491-5 ISBN 978-3-319-16492-2 (eBook)
DOI 10.1007/978-3-319-16492-2

Library of Congress Control Number: 2015934041

Springer Cham Heidelberg New York Dordrecht London

Printed on acid-free paper

Springer International Publishing AG Switzerland is part of Springer Science+Business Media
(www.springer.com)

Contents

Part I Prevention of Microbial Spreading

Part II Disinfection Techniques and Risks

Abbreviations

^{134}Cs	Caesium-134
^{137}Cs	Caesium-137
AOAC	Association of Official Analytical Chemists
A_w	Water Activity
BRC	British Retail Consortium
CCP	Critical Control Point
CIP	Clean-In-Place
ClO_2	Chlorine Dioxide
COP	Clean-Off-Place
C-PVC	Chlorinated Polyvinyl Chloride
EDTA	Ethylenediaminetetraacetic Acid
EU	European Union
FAO	Food Agriculture Organisation
FBO	Food Business Operator
FDA	Food and Drug Administration
FSA	Food Standards Agency
GMO	Genetically Modified Organism
GMP	Good Manufacturing Practice
HACCP	Hazard Analysis and Critical Control Points
HPP	High Pressure Processing
IT	Information Technology
kGy	kGray
NACMCF	National Advisory Committee on Microbiological Criteria for Foods
NaOCl	Sodium Hypochlorite
O_3–UV	Ozonisation and Ultraviolet Light
PEF	Pulsed Electric Field
ppm	Parts per million
US	United States of America

USA	United States of America
UV	Ultraviolet
WHO	World Health Organization
WIP	Washing-In-Place

Part I
Prevention of Microbial Spreading

Chapter 1
Decision Procedures and Strategies

Abstract The problem of food contamination has been thoroughly investigated in the last decades. The industrial evolution of food manufacturers and food business operators worldwide and the mutation of main social groups have caused the modification of basic food features. Moreover, the recent introduction of 'minimally processed' foods has determined the increase of possible food contamination episodes when adequate good management practices are not in place. For these reasons, the 'Hazard Analysis and Critical Control Points' approach is widely recommended with the addition of appropriate quality management systems. Because of the possibility of different hazards, a multidisciplinary approach is needed. With specific reference to microbial contamination, the problem is the eradication or the limitation of selected microorganisms depending on their pathogenic or degrading importance. Different strategies are helpful: generally, thermal treatments are considered. On the other hand, the environmental decontamination by means of cleaning and sanitisation procedures is extremely important. This chapter aims to introduce the argument of sanitising procedures in the ambit of HACCP strategies.

Keywords Cleaning · Food contamination · HACCP · Industrialisation · Microbial risk · Quality system · Sanitisation

1.1 Introduction to Safety Protocols in Food Industries

Industries develop throughout history leaving normally only results coming from a long way process. Daily foodstuffs usually have a long story based on experiences, research, studies and trials that sometimes are lost in the mists of time. The human mind gives its best when it adapts natural resources to its needs without force and conflicts.

Rarely is there the sensibility to spread the results of such a work and cultural process that started with the appearance of making on the hearth.

G. Gurnari, *Safety Protocols in the Food Industry and Emerging Concerns*,
Chemistry of Foods, DOI 10.1007/978-3-319-16492-2_1

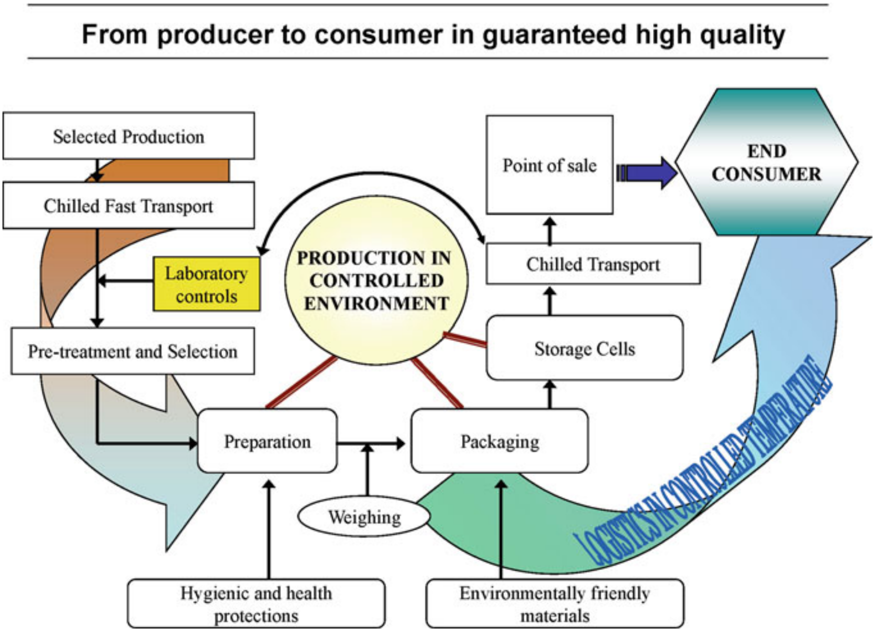


Fig. 1.1 The continuous evolution of industrial processes, from the primary production to the final distribution to consumers, has to be studied with the fundamental contribution of the current scientific knowledge. This technological approach may allow for obtaining food products with high quality and remarkable safety levels. In addition, it may be inferred that industrial food products are similar to other non-food commodities at present. The complexity of functional flowcharts appears similar in food and non-food processes. The role of logistic operations under peculiar storage conditions has to be considered

Nowadays many people try to fill this gap—sometimes wanted, sometimes happened—promoting the knowledge of some aspects of the industrial processes that currently allow providing foodstuffs totally natural and healthy.

The present contribution comes from the technological evolution and the scientific knowledge that allow carrying out top-value industrial processes, using only natural resources. New methodological approaches will be introduced in order to have healthy and safe nourishment in every production chain (Fig. 1.1).

The problem of food contamination has been thoroughly investigated in the last decades (Parish et al. 2003). Actually, the so-called ‘food contamination’ is not circumscribed to well-defined situations.

First of all, modern food production has evolved, compared with the past. In detail, the industrialisation of food manufacturers concerns probably most part of the food business operators (FBO) worldwide. The industrial evolution of FBO has been mainly determined by social factors such as the growing urban demand (Ng et al. 2014). The mutation of the main social groups has caused the modification of basic food features: reduced production and packaging times, the enhanced concentration of enormous amounts of produced foods into a single plant or working line, extended shelf life values (Barbieri et al. 2014a, b; Parisi 2002a, b; Parisi et al. 2004) and the possibility of reducing differences between various lots or batches of the same product (Ng et al. 2014).

In addition, the recent introduction on the marked of edible commodities for human consumption such as fresh-cut fruit and vegetable products, also named minimally processed foods (Allende et al. 2006; Guzewich and Ross 1999; Parish et al. 2003), has determined the increase of possible food contamination episodes when adequate and specific 'good management practices' are not in place. Substantially, fresh-cut fruits and vegetables are currently considered foods with some risk when speaking of food safety (Bhagwat 2006; FSA 2007; Gil et al. 2009). Actually, the risk of food contamination is always probable in every food and feed-production plant and correlated structures. For this reason the 'Hazard Analysis and Critical Control Points' (HACCP) approach is recommended because of the necessity for preventing contamination episodes (Parish et al. 2003). Other 'quality assurance programmes' such as the Japanese Total Quality Management (TQM) approach can be very useful when speaking of food safety and techniques for preventing risks and managing emergencies in food companies and the whole commercial system (Barendsz 1998). The evolution of quality systems, from the old ISO 9000:1994 norm to modern protocols, has determined the continuous modification of food business structures (Stilo et al. 2009). At present, it may be inferred that industrial food products are similar to other non-food commodities when speaking of basic features, standard attributes and other specifications, if stated in technical data sheets. The complexity of functional flowcharts appears similar in food and non-food processes.

The same complexity has been progressively observed in food-related sectors such as food-contact products (materials and objects). The importance of food containers should be remembered: in fact, the success—or the commercial failure—of packaged food products depends on various factors, including the container and the relationships with the packaged content (Parisi 2004). As an example, food packaging may act as a passive vehicle of microbial contamination (Parisi 2012). Other failures may concern the chemical and physical transformation of containers during processing and/or packaging processes and during the shelf life period (Parisi 2013). Another important and 'unknown' matter concerns the nature of food-contact materials when used for the production of processing and packaging machinery. This argument should be discussed by a peculiar viewpoint (Chap. 3), with relation to main components and auxiliary substances also (food-grade oils, etc.).

Food contamination can be caused by separated or synergically connected factors. The problem of food technologists is not simple because of the necessity of studying every possible cause (chemical, microbiological, physical) without interferences from other factors. This responsibility implies the reliable evaluation of obtained results and the creation of a quality management system (Parisi 2012, 2013) specifically created for food companies and other interested players in the food chain. The subsequent implementation and the re-validation of the above-mentioned food system should allow food technologists to manage predictable food contamination episodes at the least (Bratt 2010; Santana et al. 2009; Yavari et al. 2014).

In general, the HACCP approach to the problem of food crises has been thoroughly applied and implemented to a number of different food plants, sectors and subsectors in the last decades. Results have been substantially positive (Ferrara and Parisi 2004; Parisi 2002c, d), although the practical implementation of HACCP principles may be different depending on the peculiar geographical location and/or food specific types. In fact, a special attention requires the preparation of fresh vegetables for direct consumption—the so-called 'fourth range' (Bevilacqua et al. 2009)—or the preparation of product fruits and vegetables intended to be frozen (Gurnari 2004, 2005).

1.2 The Role of the HACCP Manager: Food Risks and GMP

Basically, the HACCP system is based on seven main principles (Mukundan 2005; Yavari 2014):

(1) The definition of a detailed hazard analysis for each processing step, with the aim of defining and implementing adequate control measures.
(2) The clear and reliable identification of critical control points (CCP) in the whole process, with relation to each possible risk.
(3) The definition of critical limits for each significant hazard.
(4) The definition and the implementation of reliable monitoring procedures along the process.
(5) The clear definition of preventive and corrective actions for each specified danger and hazard, when a specific CCP appears to be out of control. In detail, preventive and corrective actions are carried out with the aim of avoiding excessive values if compared with critical limits.
(6) The creation of reliable verification procedures with the aim of determining the efficacy of HACCP plans. Should the HACCP system work well, food products would be confirmed safe for human consumption.
(7) The creation of a documentation system for inspection and audit. In fact, a well-implemented HACCP plan cannot be reliable without a documentation system.

On these bases, food companies and distribution players can demonstrate the effectiveness of measures for the production of safe and legally compliant foods.

The problem of possible hazards can be very challenging. At present, many possibilities can occur, including the 'new entry' of nanotechnology in food and feed products. Anyway, the classical subdivision of risks concerns:

(a) The microbiological risk (detection and spreading of pathogen agents and degrading life forms);
(b) The chemical risk (detection of undesirable and/or dangerous chemicals in food products by different sources);
(c) The physical risk (detection of harmful foreign bodies in foods: wood fragments, glass, non-edible powders, insects, etc.).

This book is dedicated to the study of and chemical strategies for the prevention of microbial contamination in foods. As a result, the third of the above-mentioned risks is not discussed here, while the microbiological and the chemical risks are evaluated.

1.3 The Microbial Risk

The scientific literature has discussed thoroughly the problem of microbial contamination in food products (Doyle et al. 2013; Kusumaningrum et al. 2003; Lammerding and Fazil 2000; Redmond et al. 2004). In general, it may be assumed that the so-called ‘microbial risk’ in foods is the best known and investigated topic on food technology (Altekruse et al. 1996; Baglio 2014; Scott and Bloomfield 1990; Zhao et al. 1998). In fact, the same ‘food hygiene’—a matter of public safety from the medical viewpoint at least—is strictly connected with outbreaks of microbial origins and examples of chemical contamination with microbial origin: ingestion of toxins, detection of unpleasant and easily observed metabolites, etc. (Andreis and Ottaviani 2002; Bonadonna et al. 2004; Hardy 1999; Hayes 1992; Mortlock et al. 1999; Oteri and Ekanem 1989). In addition, the management of microbial spreading may be useful when speaking of shelf life prediction and control in different foods (Dalgaard et al. 1997; Parisi 2002e–g).

Basically, the management of microbial risk is needed because of at least two main reasons:

(a) Produced foods have to be safe for human consumption (Ray and Bhunia 2013). The connection between main food diseases and selected outbreaks in the last century on the one hand and the detection of dangerous or degrading microorganisms on the other hand is clearly demonstrated at present. Consequently, there is a necessity of limiting the microbial population with negative effects on human health and/or food features (Gram et al. 2002; Monk et al. 1995). A microbial population with clear and positive effects on human health and product features should be favoured (Bergamini et al. 2005; Granato et al. 2010; Salminen et al. 1998). The last situation concerns the so-called ‘probiotic’ bacteria in foods.
(b) Foods have to be also safe on the legal ground. This simple and obvious reflection implies the existence of a well-established and functional structure of regulatory protocols and supporting documents with reference to food safety and microbial contamination. As an example, the matter of microbial hygiene

> and safety indicators is thoroughly examined and ruled in the European Union (EU). With concern to this economic area only, the Commission Regulation (EC) No 2073/2005 and subsequent amendment concern microbiological criteria in foodstuffs (Montanari et al. 2015; Pisanello 2014; Jacxsens et al. 2010). All business stages—production, processing and distribution—are included. Briefly, two different criteria are defined with reference to food safety (acceptability of food products) and food hygiene (acceptability of food processing only, without recall and withdrawal consequences).

Because of the remarkable number of food rejections and notification in the EU because of microbial causes (Montanari et al. 2015), the problem of food safety has been often considered from the point of view of medical hygienists. On the other hand, the chemical risk has seemed to be underestimated until the 1990s compared with microbiological issues, except for situations with a clear connection with microbial spreading.

1.4 The Chemical Risk

The chemical risk in foods is correlated to different arguments, from the simple detection of foreign contaminants of immediate and serious concern for human health (Yan et al. 2014) to the modification of the main components of a peculiar food after processing and packaging processes.

A simplified list of common chemical contaminants is shown below, where each contaminant or class of chemicals is linked to one or more original sources (Lelieveld and Holah 2014):

(1) Toxins of microbial origin (vegetable and animal products, including crop infestation);
(2) Toxins by food-producing animals;
(3) Unexpected chemical substances in food ingredients and additives;
(4) Pesticide and veterinary residues (agricultural practices, activities of breeding livestock);
(5) Natural toxicants (from peculiar food ingredients);
(6) Dangerous and/or undesired chemicals from different reactions during processing, packaging and subsequent steps until the final consumption. These substances are often by-products of the main reactions occurring in processed and unprocessed foods;
(7) Chemical substances from unsuitable food containers;
(8) Chemical contaminants from unsuitable food contact materials (machinery, surfaces);
(9) Residual molecules of cleaning and sanitisation environmental solutions;

(10) Environmental contaminants (industrial plants, wastewater contamination, sewage, etc.);

(11) Contaminated soils (from urban, industrial and commercial activities);

(12) The presence of complex molecules denied from the mutually incompatible usage of certain chemical products.

The problem of microbial toxins from different sources is certainly one of the most important challenges in the modern food industry. Probably, the detection of mycotoxins by several fungal species appears the main emergency when speaking of adulterated foods and feeds (Joint FAO/WHO Expert Committee on Food Additives 2001; Pisanello 2014; Montanari et al. 2015). Basically, the most important group of fungal toxins appears to be represented by aflatoxins B_1, B_2, G_1, G_2, M_1 and M_2 (Goldblatt 2012; Huang et al. 2010). The biosynthesis of these chemical compounds is ascribed to certain *Aspergillus* species. Because of the remarkable acute and chronic toxicity in humans and other animal species, aflatoxins are always under strict surveillance when speaking of hygienic controls on various foods of animal and vegetable origin. Other important fungal mycotoxins are fumonisins, trichothecenes, ergot alkaloids and ochratoxins (Andreis and Ottaviani 2002; Pisanello 2014; Vasanthi and Bhat 1998).

In general, the limitation to toxin amounts (chemical and microbial risk at the same time) can only be obtained by means of the accurate selection of raw and stored commodities. Undoubtedly, many environmental factors can be monitored constantly—pH values, water activity, relative humidity in warehouses, etc.—but the rationalisation of these data can be efficacy manages in the ambit of a well-conceived and implemented HACCP plan (Murphy et al. 2006). As an example, the preharvest stage is absolutely critical from a purely technological viewpoint: HACCP plans should be always implemented from this point at least. Otherwise, the complete management approach to the limitation of toxin amounts could easily fail (Murphy et al. 2006).

Another very important point is the maintenance for facilities, devices and machinery in general (Gurnari 2006).

The matter of toxins by food-producing animals may be also discussed; however, the original cause is always the biosynthesis of different toxins by fungal species in feeding commodities (first step) and the subsequent ingestion of contaminated feeds by animals. Naturally, an important number of food rejections can be correlated to this specific mechanism. It has been reported that the transmission rate of aflatoxin B_1 by contaminated feeds determines a final excretion of this toxin in milk varieties (Weidenbörner 2001): a linear correlation between aflatoxin B_1 amounts and milk yields may be established. According to researchers, 300 μg of toxin per kg of feed may cause the detection of 4.5 μg/l in the final milk (Weidenbörner 2001).

The detection of unexpected contaminants in food ingredients and additives could be considered in the vast ambit of adulterated foods. Generally, these chemicals are not intentionally added to food commodities. On the other hand, the recent detection of melamine in Chinese milk powders (Dane and Cody 2010; Ellis et al. 2012; Langman 2009: Yang et al. 2009) is surely a desired modification of the chemical composition of food products. This situation cannot be compared with other unintentional episodes such as the occurrence of titanium dioxide in food products by different origins (environmental contamination; detection in food additives; etc.). However, the presence of these molecules may be considered in the same way because of their absolute non-food nature.

Pesticide and veterinary residues (by agricultural practices and breeding livestock) represent a current problem in food of animal origin. From the analytical viewpoint, most recent studies have been carried out with the aim of enhancing liquid chromatography and gas chromatography (coupled with mass spectrometry) multi-residue protocols when speaking of the detection and quantitative determination of pesticides such as acephate, methamidophos and triazophos (Banerjee et al. 2012; He et al. 2014; Wang et al. 2011). The eradication or the limitation of these compounds may be tried on condition that a severe monitoring plan is carried out in food production plants (Carvalho 2006).

With concern to natural toxicants from peculiar food ingredients, the simple knowledge of the correlated risk might be sufficient. On these bases, the HACCP system should manage possible situations on condition that purchased raw ingredients are strictly monitored. This strategy is also applied to allergens (Barbieri et al. 2014b; Watson 1998).

With reference to dangerous and/or undesired chemicals from different reactions during processing, packaging and subsequent steps until the final consumption, the problem is often correlated to technological transformations. The acidification of certain fatty foods is certainly due to rancidity processes and the consequent production of fatty acids from fat molecules. Remarkable amounts of toxic and volatile acrolein (National Research Council Committee on Aldehydes 1981) in fried products by the dehydration of glycerol—this molecule is obtained from triglycerides via—is well known (Hess et al. 1978; Osório and de Lourdes Cardeal 2011). The degradation of milk caseins may be very interesting when studied via normal analyses and simulative approaches (Creamer 1975; Parisi et al. 2014). Finally, an important topic is surely correlated to the production of heterocyclic amines through unstable free radical Maillard intermediates (Arvidsson et al. 1997; Kato et al. 1996; Sugimura et al. 2004; Weisburger 2002). Because of the apparently wide applicability of Maillard reactions in many foods and edible sub-categories of foods, this argument should be discussed in detail. Anyway, the emersion of similar problems highlights the necessity of profound studies from an interdisciplinary viewpoint, without reference to a single product category.

Contamination of food products by simple contact with non-edible surfaces concerns the use of unsuitable food containers (Parisi 2004, 2012, 2013). Actually, similar failures may be also caused by other factors: food packaging materials may be technologically suitable for intended use. However, different storage conditions and the simple—but often observed—mutation of food compositions and types, including also the modification of sizes, may determine unexpected results (Brunazzi et al. 2014a, b; Parisi 2012). When speaking of food contact, the role of food processing machinery and correlated parts has to be necessarily evaluated. In fact, the discussion should equally consider three different aspects:

(a) The suitability of food packaging objects and materials for food processing and packaging equipments, with the exclusion of food-contact containers.
(b) The hygienic design of food processing and packaging machinery (including the choice of materials).
(c) The correct cleaning and sanitisation of food-contact surfaces (including the quality of chemical products).

The last point concerns the possible detection of residual molecules of cleaning and sanitisation solutions in foods. In addition, the microbial contamination may be also determined by incorrect cleaning and sanitisation procedures (wrong times of applications; incorrect dilution ratio; unexpected chemical reaction due to simultaneous use of different substances; etc.).

Finally, environmental contaminants by industrial plants and other non-food plants should be considered. This discussion concerns mainly the correct management of external contamination outside food plants, warehouses and other food-correlated areas. For example, air pollution—production of dioxins and similar toxic compounds—may be a challenging problem (Fu et al. 2008) when a food plant is located in a particular area where one or more waste treatment activities (incineration, etc.) are found. The same problem can be discussed in relation to the most recent nuclear incidents in the *Chernobyl* and *Fukushima Dai-ichi* power plants. In particular, different researches have been carried out recently in relation to the impact of radioactive caesium on Japanese food and feed products. With regard to human health effects, one of the main reasons has been the comparison between the different situations in *Fukushima* and *Chernobyl*: in fact, the Ukrainian accident has been extensively studied and many researches are available at present. On the other hand, the effect on Japanese food and feed products should be carefully investigated and compared with the previous *Chernobyl* situation.

At present, existing studies have highlighted that:

(a) One of the most contaminated products is brown rice (*Oryza sativa* L.) grown in the *Fukushima* Prefecture and in the nearby areas (Nemoto and Abe 2013). The radiocaesium contamination has exceeded 500 Bq/kg (the provisional legal level) in this food product. Actually, this result is surprising because radioactive materials, including caesium, are strongly bound to soil granules. As a result, crops and plants do not show high contamination levels if caesium is absorbed through roots (Nemoto and Abe 2013). One of the most probable causes could be correlated to the durable contamination of waters in paddy fields for some period, with consequent notable root absorption. In fact, other Japanese products have been found to show radiocaesium contamination. One of these foods, extremely popular in Japan and well-known abroad is wasabi (*Eutrema wasabi*): this vegetable product is often cultured using water from mountains. The notable detection of radionuclides in these products can suggest the necessity for higher inspection levels. In addition, suspended matter and particulate organic matter appear to be (Ohte et al. 2013) the most important carriers of caesium-137 (^{137}Cs)

(b) It has been suggested that sulphate may be a potential aerosolised carrier for caesium-134 (^{134}Cs) and ^{137}Cs. As a result, contaminated areas, such as cities and urban regions, with notable presence of aerosolised sulfate may also transport the efficacy of these radionuclides. Cultivated plants and related food and feed products might be remarkably contaminated (Kaneyasu et al. 2012)

(c) Agricultural practices should be rapidly changed with the aim of reducing detectable radioactivity. In fact, the use of potassium in paddy soils can notably reduce root absorption of ^{134}Cs and ^{137}Cs. As a clear consequence, rice plants show reduced contamination by radionuclides (Kobayashi 2013). The addition of absorbents may be also useful because of the predictable contamination of soils during time: ^{137}Cs is a radionuclide with a half-life of 30 years (Nihei 2013)

(d) Cereals and mushrooms are expected to remain under observation in the next future. With reference to rice, the durable contamination of soils is a sufficient argument. In addition, mushrooms have been found to show residual ^{137}Cs radioactivity after nuclear weapon tests in the 1950s (Yamada 2013).

1.5 Microbial Decontamination and Related Risks

At present, one of the basic and necessary instruments for the eradication or the limitation of microbial decontamination is represented by cleaning and sanitisation procedures. This approach may seem too simplified: in fact, the simple word 'decontamination' seems to suggest the necessity for eliminating microorganisms when present (in foods, food-contact surfaces, air, water, etc.). As a result, thermal treatments and other technological procedures for elimination or reduction of microbial counts may be omitted.

Basically, microbial contamination may be reduced by means of the following techniques and/or procedures in food plants and in dedicated warehouses (Evans et al. 2004; Scott and Bloomfield 1990):

(1) Correct selection of raw ingredients and packaging materials;
(2) Separation between different areas;
(3) Prevention of cross-contamination episodes between different lines dedicated to the production of dissimilar foods;
(4) Prevention of survival and transfer of microscopic life forms via cloths, hands and utensils;
(5) Prevention of microbial contamination by food refrigeration equipment;
(6) Use of thermal processing treatments and/or preserving technologies (smoking, salting, etc.);
(7) Use of purified water and modern techniques (sonication, etc.);
(8) Purification of atmospheric gases and prevention of aerosolised suspensions

(9) Creation and implementation of correct cleaning and sanitising procedures
(10) Special prevention procedures should be used in a productive sector, particularly sensitive, as that of bottling water. Natural mineral water must be regarded as a real food (for contributions determined by micro and macroelements minerals, some of which are essential for human health), particularly easy for contamination and itself source derivatives of both organic and inorganic if not sufficiently protected (Gurnari 2002; Zanasi et al. 2013).

The above list may not be exhaustive but covers many of the modern strategies for the limitation of microbial counts in foods. Unfortunately, each approach or method may reduce a specified microbial risk but other failures can occur at the same time. The aim of this book is to give a reliable overview of different strategies with related advantages and drawbacks.

References

Allende A, Tomás-Barberán FA, Gil MI (2006) Minimal processing for healthy traditional foods. Trends Food Sci Technol 17(9):513–519. doi:10.1016/j.tifs.2006.04.005

Altekruse SF, Street DA, Fein SB, Levy AS (1996) Consumer knowledge of foodborne microbial hazards and food-handling practices. J Food Prot 59(3):287–294

Andreis G, Ottaviani F (eds) (2002) Manuale delle Sicurezza Microbiologica degli Alimenti e delle Acque. Oxoid SpA, Garbagnate M.se

Arvidsson P, Van Boekel MAJS, Skog K, Jägerstad M (1997) Kinetics of formation of polar heterocyclic amines in a meat model system. J Food Sci 62(5):911–916. doi:10.1111/j.1365-2621.1997.tb15005.x

Baglio E (2014) The modern yoghurt: introduction to fermentative processes. In: Baglio E (ed) Chemistry and technology of yoghurt fermentation. SpringerBriefs in Chemistry of Foods. Springer, Heidelberg

Banerjee K, Utture S, Dasgupta S, Kandaswamy C, Pradhan S, Kulkarni S, Adsule P (2012) Multiresidue determination of 375 organic contaminants including pesticides, polychlorinated biphenyls and polyaromatic hydrocarbons in fruits and vegetables by gas chromatography–triple quadrupole mass spectrometry with introduction of semi-quantification approach. J Chromatogr A 1270:283–295. doi:10.1016/j.chroma.2012.10.066

Barbieri G, Barone C, Bhagat A, Caruso G, Conley ZR, Parisi S (2014a) The prediction of shelf life values in function of the chemical composition in soft cheeses. In: Barbieri G, Barone C, Bhagat A, Caruso G, Conley ZR, Parisi S (eds) The influence of chemistry on new foods and traditional products. SpringerBriefs in Chemistry of Foods. Springer, Heidelberg

Barbieri G, Barone C, Bhagat A, Caruso G, Conley ZR, Parisi S (2014b) Food manufacturing and allergen management. In: Barbieri G, Barone C, Bhagat A, Caruso G, Conley ZR, Parisi S (eds) The influence of chemistry on new foods and traditional products. SpringerBriefs in Chemistry of Foods. Springer, Heidelberg (in press)

Barendsz AW (1998) Food safety and total quality management. Food Control 9(2):163–170. doi:10.1016/S0956-7135(97)00074-1

Bergamini CV, Hynes ER, Quiberoni A, Suárez VB, Zalazar CA (2005) Probiotic bacteria as adjunct starters: influence of the addition methodology on their survival in a semi-hard Argentinean cheese. Food Res Int 38(5):597–604. doi:10.1016/j.foodres.2004.11.013

Bevilacqua M, Ciarapica FE, Giacchetta G (2009) Business process reengineering of a supply chain and a traceability system: a case study. J Food Eng 93(1):13–22. doi:10.1016/j.jfoodeng.2008.12.020

Bhagwat AA (2006) Microbiological safety of fresh-cut produce: where are we now? In: Matthews KR (ed) Microbiology of fresh produce. ASM Press, Washington, DC, pp 121–165

Bonadonna L, Briancesco R, Donia D, Ottaviani M, Veschettt E, Divizia M (2004) Aspetti igienico-sanitari delle acque del fiume Tevere: presenza di protozoi patogeni e rapporti di correlazione con parametri microbiologici e chimico-fisici. Ann Ig 16(1–2):273–280

Bratt L (ed) (2010) Fish canning handbook. Wiley, Oxford. doi:10.1002/9781444323405

Brunazzi G, Parisi S, Pereno A (2014a) Packaging and food: a complex combination. In: Brunazzi G, Parisi S, Pereno A (eds) The importance of packaging design for the chemistry of food products. SpringerBriefs in Chemistry of Foods. Springer, Heidelberg, pp 7–56. doi:10.1007/978-3-319-08452-7_2

Brunazzi G, Parisi S, Pereno A (2014b) The instrumental role of food packaging. In: Brunazzi G, Parisi S, Pereno A (ed) The importance of packaging design for the chemistry of food products. SpringerBriefs in Chemistry of Foods. Springer, Heidelberg, pp 7–56. doi:10.1007/978-3-319-08452-7_3

Carvalho FP (2006) Agriculture, pesticides, food security and food safety. Environ Sci Policy 9 (7):685–692. doi:10.1016/j.envsci.2006.08.002

Creamer LK (1975) β-Casein degradation in gouda and cheddar cheese. J Dairy Sci 58(3):287–292. doi:10.3168/jds.S0022-0302(75)84562-0

Dalgaard P, Mejlholm O, Huss HH (1997) Application of an iterative approach for development of a microbial model predicting the shelf-life of packed fish. Int J Food Microbiol 38(2):169–179. doi:10.1016/S0168-1605(97)00101-3

Dane AJ, Cody RB (2010) Selective ionization of melamine in powdered milk by using argon direct analysis in real time (DART) mass spectrometry. Analyst 135:696–699. doi:10.1039/B923561B

Doyle MP, Beuchat LR, Montville TM (eds) (2013) Food microbiology: fundamentals and frontiers. American Society for Microbiology, Washington, DC

Ellis DI, Brewster VL, Dunn WB, Allwood JW, Golovanov AP, Goodacre R (2012) Fingerprinting food: current technologies for the detection of food adulteration and contamination. Chem Soc Rev 41(17):5706–5727. doi:10.1039/C2CS35138B

Evans JA, Russell SL, James C, Corry JE (2004) Microbial contamination of food refrigeration equipment. J Food Eng 62(3):225–232. doi:10.1016/S0260-8774(03)00235-8

Ferrara M, Parisi S (2004) Coliformi totali nei dolci tipici siciliani: effetti della sorveglianza microbiologica nel quadriennio 2000–2003. In: Proceedings of the thirteenth national conference ‘I rischi microbiologici del 2000 nel settore alimentare’, Bologna, Oxoid S.p.A., pp 97–102

FSA (2007) Morrisons recalls leaf salad. Food Standards Agency, UK. http://www.food.gov.uk/news/newsarchive/2007/apr/morrisalad. Accessed 12 Jan 2015

Fu J, Zhou Q, Liu J, Liu W, Wang T, Zhang Q, Jiang G (2008) High levels of heavy metals in rice (Oryza sativa L.) from a typical E-waste recycling area in southeast China and its potential risk to human health. Chemosphere 71(7):29–1275. doi:10.1016/j.chemosphere.2007.11.065

Gil MI, Selma MV, López-Gálvez F, Allende A (2009) Fresh-cut product sanitation and wash water disinfection: problems and solutions. Int J Food Microbiol 134(1):37–45. doi:10.1016/j.ijfoodmicro.2009.05.021

Goldblatt L (ed) (2012) Aflatoxin: scientific background, control, and implications. Academic press Inc., New York

Gram L, Ravn L, Rasch M, Bruhn JB, Christensen AB, Givskov M (2002) Food spoilage-interactions between food spoilage bacteria. Int J Food Microbiol 78(1):79–97. doi:10.1016/S0168-1605(02)00233-7

Granato D, Branco GF, Nazzaro F, Cruz AG, Faria JA (2010) Functional foods and nondairy probiotic food development: trends, concepts, and products. Compr Rev Food Sci Food Saf 9 (3):292–302. doi:10.1111/j.1541-4337.2010.00110.x

Gurnari G (2002) Le Utilities. Acque minerali e di sorgente Italia. Beverfood edizioni, Milan

Gurnari G (2004) La sfida produttiva. Paper presented at the MIA ’04, Fiera di Rimini, Rimini

Gurnari G (2005) Healthness® e tecnologia per il cibo. Paper presented at the 17th ‘Festival del Fitness’, Rimini

Gurnari G (2006) New food generation. L'evoluzione culturale nella tecnologia per il mercato del salutismo. Paper presented at the 'New food generation: la salute prende forma' International Congress, Rimini, 10th June 2006

Guzewich J, Ross MP (1999) Evaluation of risks related to microbiological contamination of ready-to-eat food by food preparation workers and the effectiveness of interventions to minimize those risks. U.S. Food and Drug Administration, Center for Food Safety and Applied Nutrition

Hardy A (1999) Food, hygiene, and the laboratory. A short history of food poisoning in Britain, circa 1850–1950. Soc Hist Med 12(2):293–311. doi:10.1093/shm/12.2.293

Hayes R (1992) Food microbiology and hygiene. Elsevier Applied Science Publishers, London

He Z, Wang L, Peng Y, Luo M, Wang W, Liu X (2014) Multiresidue analysis of over 200 pesticides in cereals using a QuEChERS and gas chromatography-tandem mass spectrometry-based method. Food Chem 169:372–380. doi:10.1016/j.foodchem.2014.07.10

Hess LG, Kurtz AN, Stanton DB (1978) Acrolein and derivatives. In: Grayson M, Eckroth D (eds) Kirk-Othmer encyclopedia of chemical technology, vol 1, 3rd edn. Wiley, New York, pp 277–297

Huang B, Han Z, Cai Z, Wu Y, Ren Y (2010) Simultaneous determination of aflatoxins B1, B2, G1, G2, M1 and M2 in peanuts and their derivative products by ultra-high-performance liquid chromatography–tandem mass spectrometry. Anal Chim Acta 662(1):62–68. doi:10.1016/j.aca.2010.01.002

Kaneyasu N, Ohashi H, Suzuki F, Okuda T, Ikemori F (2012) Sulfate aerosol as a potential transport medium of radiocesium from the Fukushima nuclear accident. Environ Sci Technol 46(11):5720–5726. doi:10.1021/es204667h

Kato T, Harashima T, Moriya N, Kikugawa K, Hiramoto K (1996) Formation of the mutagenic/carcinogenic imidazoquinoxaline-type heterocyclic amines through the unstable free radical Maillard intermediates and its inhibition by phenolic antioxidants. Carcinogenesis 17(11):2469–2476

Kobayashi NI (2013) Time-course analysis of radiocesium uptake and translocation in rice by radioisotope imaging. In: Nakanishi TM, Tanoi K (eds) Agricultural implications of the Fukushima nuclear accident. Springer, Tokio

Kusumaningrum HD, Riboldi G, Hazeleger WC, Beumer RR (2003) Survival of foodborne pathogens on stainless steel surfaces and cross-contamination to foods. Int J Food Microbiol 85(3):227–236. doi:10.1016/S0168-1605(02)00540-8

Jacxsens L, Uyttendaele M, Devlieghere F, Rovira J, Gomez S, Luning PA (2010) Food safety performance indicators to benchmark food safety output of food safety management systems. Int J Food Microbiol 141(S1):180–187. doi:10.1016/j.ijfoodmicro.2010.05.003

Joint FAO/WHO Expert Committee on Food Additives (2001) Safety evaluation of certain mycotoxins in food. FAO Food and Nutrition Paper, vol 74. World Health Organization (WHO), Geneva; Food and Agriculture Organization (FAO), Rome

Lammerding AM, Fazil A (2000) Hazard identification and exposure assessment for microbial food safety risk assessment. Int J Food Microbiol 58(3):147–157. doi:10.1016/S0168-1605(00)00269-5

Langman CB (2009) Melamine, powdered milk, and nephrolithiasis in Chinese infants. N Engl J Med 360(11):1139–1141. doi:10.1056/NEJMe0900361

Lelieveld HLM, Holah JT (2014) Hazard, sources and vectors of contamination. In: Lelieveld H, Holah JT, Napper D (eds) Hygiene in food processing: principles and practice, 2nd edn. Woodhead Publishing Ltd, Cambridge

Monk JD, Beuchat LR, Doyle MP (1995) Irradiation inactivation of food-borne microorganisms. J Food Prot 58(2):197–208

Montanari F, Jezsó V, Donati C (2015) Risk regulation in non-animal food imports. The european union approach. SpringerBriefs in Chemistry of Foods. Springer, Heidelberg (in press)

Mortlock MP, Peters AC, Griffith CJ (1999) Food hygiene and hazard analysis critical control point in the United Kingdom food industry: practices, perceptions, and attitudes. J Food Prot 62(7):786–792

Mukundan MK (2005) Quality and safety in indian seafood industry. Central institute of fisheries technology (CIFT), CIFT winter school. http://210.212.228.207/bitstream/handle/123456789/1244/Quality%20and%20safety%20in%20Indian%20seafood%20industry.pdf?sequence=1. Accessed 12 Jan 2015

Murphy PA, Hendrich S, Landgren C, Bryant CM (2006) Food mycotoxins: an update. J Food Sci 71(5):R51–R65. doi/10.1111/j.1750-3841.2006.00052.x

National Research Council Committee on Aldehydes (1981) Formaldehyde and other aldehydes. National Academy of Sciences Press, Washington, DC

Nemoto K, Abe J (2013) Radiocesium absorption by rice in paddy field ecosystems. In: Nakanishi TM, Tanoi K (eds) Agricultural implications of the Fukushima nuclear accident. Springer, Tokio

Ng MX, Ong SP, Hii CL, Chuah LA, Law CL (2014) Review of food toxicological issues associated in rubber products. In: Proceedings of the 3rd international symposium on processing of foods, vegetables and fruits (ISPFVF 2014), University of Nottingham Malaysia Campus, 11–13 August 2014. http://eprints.nottingham.ac.uk/3387/1/ISPFVF_Paper-%28NMX%29.pdf. Accessed 12 Jan 2015

Nihei N (2013) Radioactivity in agricultural products in Fukushima. In: Nakanishi TM, Tanoi K (eds) Agricultural implications of the Fukushima nu-clear accident. Springer, Tokio

Ohte N, Murakami M, Suzuki T, Iseda K, Tanoi K, Ishii N (2013) Diffusion and transportation dynamics of 137Cs deposited on the forested area in Fukushima after the Fukushima Daiichi nuclear power plant accident in march 2011. In: Nakanishi TM, Tanoi K (eds) Agricultural implications of the Fukushima nuclear accident. Springer, Tokio

Osório VM, de Lourdes Cardeal Z (2011) Determination of acrolein in french fries by solid-phase microextraction gas chromatography and mass spectrometry. J Chromatogr A 1218(21):3332–3336. doi:10.1016/j.chroma.2010.11.068

Oteri T, Ekanem EE (1989) Food hygiene behaviour among hospital food handlers. Pub Health 103(3):153–159. doi:10.1016/S0033-3506(89)80069-1

Parish ME, Beuchat LR, Suslow TV, Harris LJ, Garrett EH, Farber JN, Busta FF (2003) Methods to reduce/eliminate pathogens from fresh and fresh-cut produce. Compr Rev Food Sci Food Saf 2(s1):161–173. doi:10.1111/j.1541-4337.2003.tb00033.x

Parisi S (2002a) Profili evolutivi dei contenuti batterici e chimico-fisici in prodotti lattiero-caseari. Ind Aliment 412:295–306

Parisi S (2002b) I fondamenti del calcolo della data di scadenza degli alimenti: principi ed applicazioni. Ind Aliment 417:905–919

Parisi S (2002c) Studio comparativo tra vari metodi sul monitoraggio igienico delle superfici nel comparto lattiero-caseario. In: Proceedings of the conference 'Monitoraggio ambientale e controllo qualità nel comparto lattiero-caseario', 13th June 2002. Società Italiana di Microbiologia Applicata, International Pbi, Milan

Parisi S (2002d) La stesura del Piano di Autocontrollo nel comparto agro-alimentare. Il Chimico Italiano XIII, 2:25–28

Parisi S (2002e) Previsione della crescita della flora microbica non lattica in formaggi. Ind Aliment 419:1195–1203

Parisi S (2002f) Curve predittive per la crescita dei batteri Coliformi in prodotti lattiero-caseari. Ind Aliment 421:29–37

Parisi S (2002g) The prediction of minimum durability in dairy products through analysis of bacterial and chemical—physical contents. Ital Food Technol 29:5–14

Parisi S (2004) Alterazioni in imballaggi metallici termicamente processati. Gulotta Press, Palermo

Parisi S (2012) Food packaging and food alterations. The User-Oriented Approach. Smithers Rapra Technology Ltd, Shawbury

Parisi S (2013) Food industry and packaging materials: user-oriented guidelines for users. Smithers Rapra Technology Ltd, Shawbury

Parisi S, Delia S, Laganà P (2004) Il calcolo della data di scadenza degli alimenti: la funzione Shelf Life e la propagazione degli errori sperimentali. Ind Aliment 438:735–749

Parisi S, Barone C, Caruso G (2014) The problem of the aqueous absorption in processed cheeses. A simulated approach. In: Barbieri G, Barone C, Bhagat A, Caruso G, Conley ZR, Parisi S (eds) The influence of chemistry on new foods and traditional products. SpringerBriefs in Chemistry of Foods. Springer, Heidelberg

Pisanello D (2014) Chemistry of foods: EU legal and regulatory approaches. SpringerBriefs in Chemistry of Foods. Springer, Heidelberg

Ray B, Bhunia A (2013) Fundamental food microbiology. CRC Press, Boca Raton

Redmond EC, Griffith CJ, Slader J, Humphrey TJ (2004) Microbiological and observational analysis of cross contamination risks during domestic food preparation. Br Food J 106(8):581–597. doi:10.1108/00070700410553585

Salminen S, Bouley C, Boutron MC, Cummings JH, Franck A, Gibson GR, Isolauria E, Moreau MC, Roberfroid M, Rowland I (1998) Functional food science and gastrointestinal physiology and function. Br J Nutr 80(S1):S147–S171. doi:10.1079/BJN19980108

Santana NG, Almeida RC, Ferreira JS, Almeida PF (2009) Microbiological quality and safety of meals served to children and adoption of good manufacturing practices in public school catering in Brazil. Food Control 20(3):255–261. doi:10.1016/j.foodcont.2008.05.004

Scott E, Bloomfield SF (1990) The survival and transfer of microbial contamination via cloths, hands and utensils. J Appl Bacteriol 68(3):271–278. doi:10.1111/j.1365-2672.1990.tb02574.x

Stilo A, Parisi S, Delia S, Anastasi F, Bruno G, Laganà P (2009) Food security in Europe: comparison between the “Hygiene Package” and the British Retail Consortium (BRC) and International Food Standard (IFS) protocols. Ann Ig 21(4):387–401

Sugimura T, Wakabayashi K, Nakagama H, Nagao M (2004) Heterocyclic amines: mutagens/carcinogens produced during cooking of meat and fish. Cancer Sci 95(4):290–299. doi:10.1111/j.1349-7006.2004.tb03205.x

Vasanthi S, Bhat RV (1998) Mycotoxins in foods–occurrence, health and economic significance and food control measures. Indian J Med medical Res 108:212–224

Yamada T (2013) Mushrooms: Radioactive Contamination of wide-spread mushrooms in Japan. In: Nakanishi TM, Tanoi K (eds) Agricultural implications of the Fukushima nuclear accident. Springer, Tokio

Yan Z, Sheng W, Xiao L, YanNi M, Ping L, YongGang L, Ming C, TingMing S (2014) Review on the risk assessment for chemical contaminants in food. J Food Saf Qual 5(6):1868–1875

Yang SP, Ding JH, Zheng J, Hu B, Li JQ, Chen HW, Zhou ZQ, Qiao XL (2009) Detection of melamine in milk products by surface desorption atmospheric pressure chemical ionization mass spectrometry. Anal Chem 81:2426–2436. doi:10.1021/ac900063u

Yavari H, Khaniki GJ, Mohseni M, Kamali K (2014) Implementation of hazard analysis critical control point in one of the Iranian flight catering establishment: technical barriers and strategies. J Food Saf Hyg 1(1):1–7

Wang Y, Jin HY, Ma SC, Lu J, Lin RC (2011) Determination of 195 pesticide residues in Chinese herbs by gas chromatography–mass spectrometry using analyte protectants. J Chromatogr A 1218(2):334–342. doi:10.1016/j.chroma.2010.11.036

Watson DH (ed) (1998) Natural toxicants in food, vol 2. Sheffield Academic Press, Sheffield

Weidenbörner M (2001) Encyclopedia of Food Mycotoxins. Springer, Berlin

Weisburger JH (2002) Comments on the history and importance of aromatic and heterocyclic amines in public health. Mutat Res/Fundam Mol Mech Mutagen 506:9–20. doi:10.1016/S0027-5107(02)00147-1

Zanasi A, Aprile A, Gurnari G, Parola S (2013) Guida alle acque minerali ita-liane in bottiglia, edition 2013. Servizi GM (ed), Bologna

Zhao P, Zhao T, Doyle MP, Rubino JR, Meng J (1998) Development of a model for evaluation of microbial cross-contamination in the kitchen. J Food Prot 61(8):960–963

Chapter 2
The Reduction of Microbial Spreading: Little Details, Great Effects

Abstract The eradication or the limitation of microbial contamination into food industries and dedicated warehouses may be reduced by means of a multidisciplinary and integrated management approach. In the ambit of the so-called 'Hazard analysis and critical control points' plan, different instruments and procedures may be applied with interesting results. The reliable selection of raw ingredients, including reusable (recycled) waters and packaging materials, has to be perceived as the first pilaster of a well-designed and implemented HACCP plan. Moreover, other aspects correlated to the prevention and minimisation of microbial spread into food production areas have to be considered: the separation between different areas in the same industry; the problem of cross-contamination between different lines, including the necessity of limiting aerosolised suspensions; the possible survival (and transfer) of microscopic life forms via cloths, hands, utensils and food refrigeration equipment; the creation and implementation of correct cleaning and sanitising procedures. These aspects of the modern challenge to microbial spreading and contamination episodes in food industries are briefly discussed in this chapter.

Keywords Aerosol · Biofilm · Protobiofilm · Food business operator · Good manufacturing practice · HACCP · Microbial spreading · Purified water

2.1 Basic Strategies Against Microbial Spreading in Food Industries: An Overview

At present, the eradication or the limitation of microbial contamination in food industries and dedicated warehouses (Sect. 1.5) may be at least reduced by means of the following techniques and/or procedures (Evans et al. 2004; Scott and Bloomfield 1990):

(1) Correct selection of raw ingredients and packaging materials;
(2) Separation between different areas;

G. Gurnari, *Safety Protocols in the Food Industry and Emerging Concerns*,
Chemistry of Foods, DOI 10.1007/978-3-319-16492-2_2

(3) Prevention of cross-contamination episodes between different lines dedicated to the production of dissimilar foods;
(4) Prevention of survival and transfer of microscopic life forms via cloths, hands and utensils;
(5) Prevention of microbial contamination by food refrigeration equipment;
(6) Use of thermal processing treatments and/or preserving technologies (smoking, salting, etc.);
(7) Use of purified water and modern techniques (sonication, etc.);
(8) Purification of atmospheric gases and prevention of aerosolised suspensions;
(9) Creation and implementation of correct cleaning and sanitising procedures.

This list covers many of the modern strategies for the limitation of microbial counts in foods. Unfortunately, each approach or method may reduce a specified microbial risk but other failures can occur at the same time (Sect. 1.5). The aim of this book is to give a reliable overview of different strategies with related advantages and drawbacks.

2.2 Correct Selection of Raw Ingredients and Packaging Materials

Basically, the main source of microbial contamination of food products (pathogen and degrading life forms, viruses, etc.) should be researched in the ambit of the primary production.

This approach is particularly important when speaking of pathogenic contamination. Because of the remarkable importance of certain microorganisms in connection with peculiar outbreaks such as the recent 2011-*Escherichia coli* crisis in Europe (Montanari et al. 2015; Pisanello 2014), the identification of original contamination sources is one of the main pilasters of the ‘hazard analysis and critical control points’ (HACCP) approach to the problem of food production and distribution. As an example, the detection of *Listeria monocytogenes* in different foods (meat products, etc.) may be correlated with environmental samples, including vegetation, faeces and meat (Fenlon et al. 1996). The same can be easily affirmed with relation to *Campylobacter* colonisation in poultry products (Wagenaar et al. 2008) and the recent *E. coli* O157:H7 outbreaks. With regard to the last microorganism, the use of contaminated water during irrigation, propagation or washing (Fig. 2.1) has been considered since 1999 (Food and Drug Administration 1999; Kirby et al. 2003).

Generally, the main environmental sources of microbial contamination are recognised as follows (Kirby et al. 2003):

- Water intended for primary production facilities (aquaculture, irrigation, etc.);
- Water intended for food processing plants and operations (bottling, cooling, washing, production of ice, cleaning, sanitisation, etc.);

Fig. 2.1 The detection of *Listeria monocytogenes* and other pathogens such as *E. coli* O157:H7 in different foods may be correlated with environmental samples, including vegetation and waters. The use of contaminated water during washing processes has been considered since 1999

- Recycled water;
- Feeding products intended for animal nutrition;
- Contaminated raw ingredients for food production;
- Contaminated food packaging materials and objects;
- Contaminated machinery and related parts;
- Contaminated air (aerosolised suspensions);
- Other causes, including hygienic conditions of factory workers;
- Surface water flow (pattern, drainages, water stagnation, etc.);
- Collection drains/discharges and sewerage);
- Proximity of uncontrolled waste dumps.

The matter of water decontamination is discussed here in detail with other measures concerning the segregation of different areas and aerosolised suspensions. Moreover, contamination by raw materials and feeding products should be discussed in the vast ambit of HACCP strategies (Chap. 4). In addition, the hygiene of food-contact approved materials for machinery is described in Chap. 3.

In regard to water supplies, normal countermeasures are explained briefly as follows.

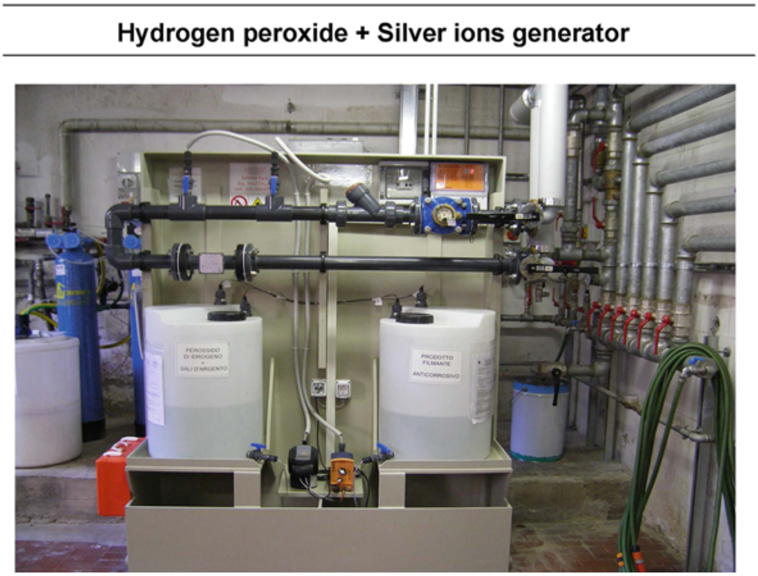
Water treatments are carried out mainly with the aim of protecting consumers and foods from microbial pathogens and from chemical and physical impurities (Kirby et al. 2003). Actually, the scope should also comprehend the limitation of microbial spread from degrading life forms without dangers for human health. Generally, the treatment of waters for food production (with the exclusion of wastewater) concerns the following operations (Kirby et al. 2003; World Health Organization 1996):

- Coagulation
- Sedimentation
- Filtration
- Other advanced treatments (activated carbon, ion exchange, membrane filtration, reverse osmosis, etc.)
- Final disinfection (oxidation, ultraviolet light, heating processes, use of caustic substances, etc.).

According to current HACCP approaches, a sufficient supply of potable water is strictly required (Kirby et al. 2003; World Health Organization 1996). For this reason food plants without primary production have to rely on this important 'ingredient' (Poretti 1990). Potable water is also present in foods after incorporation: one of these situations concerns the production of *pasta filata* cheeses. Original raw materials, cow's milk curds, are 'washed' in hot water, but a certain amount of water is adsorbed by proteins (Barbieri et al. 2014a). Consequently, publicly available potable waters are often used in food plants. On the other hand, food business operators (FBO) without available waters may be forced to reuse or recycle their water supplies when allowed by HACCP plans. In fact, the use and reuse of waters in food production and processing steps should be evaluated using the HACCP approach because of the clear and well-demonstrated connection between water and food-borne diseases (Kirby et al. 2003). Anyway, recycled or reused water should not affect food safety and the general (accepted) quality of product (Codex Alimentarius Commission 2000). For these reasons, a certain amount of analytical tests are required with the aim of assuring safety and quality, depending on risk assessment and HACCP evaluations. Because of the importance of the final destination (reuse) of water, the frequency of analyses should be carefully evaluated. In addition, reused water has to be sanitised when intended for container cooling operations (Kirby et al. 2003).

Particular attention should be given with regard to water decontamination in food plants. In fact, the complete purification or production of potable water is not possible in several food production environments. For this reason, FBO can reasonably use only a few selected methods for decontaminating water supplies from the microbiological viewpoint at least among these systems (Amjad 1993; Casani et al. 2005; Gupta and Ako 2005; Huang et al. 2008):

- Sedimentation and filtration
- Ion exchange
- Ultraviolet (UV) light
- Reverse osmosis
- Membrane filtration
- Lime treatment
- Flocculation with selected aid such as guar gums (with relation to chemical purification)



Hydrogen peroxide + Silver ions generator

Fig. 2.2 Water decontamination in food plants has to be considered as one of the main pilasters of food safety. The complete purification or production of potable water is not possible in several food production environments. For this reason, food business operators can reasonably use only a few selected methods for decontaminating water supplies from the microbiological viewpoint. One of these strategies is the use of innovative systems such as hydrogen peroxide and silver ion generators

- Complete disinfection (oxidising chemicals, UV light, caustic chemicals, heating processes, etc.)
- Innovative systems (Gurnari 2006): electrolysed water, ozonisation, synergic ozonisation and ultraviolet light (O_3–UV) treatment, hydrogen peroxide and silver ions, etc. (Fig. 2.2).

Other methods may be the use of selected antimicrobials in waters: chitin, chitosan and their derivatives such as hydroxypropyl chitosan have been already proposed (Kamble et al. 2007; Onsosyen and Skaugrud 1990; Shahidi et al. 1999; Xie et al. 2002) for the purification of water (removal of metallic cations, pesticides, polychlorobiphenyls and phenols and dyes) and the observed antibacterial activity. However, the full application of these chemicals for water supplies in the industrial field should be evaluated in the future because of economic implications and technological difficulties.

At present, physical and chemical methods appear the most used technologies for the prevention of water contamination (and recontamination) in food plants. However, it should be noted that the preferential direction seems to favour synergic systems: the ‘oxidising chemicals/UV light/heating process’ combination and other systems appear as good choices in big and medium-sized industries. On the other hand, little plants seem to prefer one single apparatus instead of synergic disinfection methods, with the possible addition of chlorinated water at some points in processes. With regard to these industries, the best strategy is always correlated to the microbial (or chemical) risk on the one hand, and the necessity of minimising water consumption and wastewater discharge rates (Gil et al. 2009). The reduction of wastewater rates is generally dependent on the employed disinfection technique (Gil et al. 2009; Ölmez and Kretzschmar 2009). On the other hand, the best disinfection technique should be defined on the basis of the following factors (Gil et al. 2009):

(a) Chemical contents
(b) Water consumption
(c) Water use (example: washing)
(d) The desired result in terms of quantitative reduction (log units) of microbial counts and qualitative eradication of targeted bacteria (*E. coli* and F-specific coliphage MS2, *Salmonella* spp., *L. monocytogenes*, *Pseudomonas fluorescens*, *Enterobacteriaceae*, *Aeromonas* spp., Hepatitis A, natural microflora, etc.)
(e) Diffusion of supplied water along the process flowchart
(f) The final food product
(g) Water supply system and its source (Spica et al. 2012).

2.3 Segregation of Raw Materials

According to HACCP principles and the most recent quality standards (Barbieri et al. 2014b; Materia et al. 2009; Parisi 2002; Parisi et al. 2009a, b, c; Stilo et al. 2009), the microbial risk of food contamination by different raw ingredients and materials may be managed and limited by means of segregation procedures. In detail, the delimitation of food plants, warehouses and retail spaces into high/low-risk areas (or clean/dirty areas) may be very useful (Bratt 2010) when speaking of the eradication or limitation of the following phenomena (Sect. 2.1):

- Cross-contamination of raw ingredients for food production;
- Cross-contamination of packaging materials and objects contacts;
- Cross-contamination of processing machinery and related parts;
- Air contamination (aerosolised suspensions);
- Contact time and exposure time;
- Micro-climatic conditions.

Substantially, the separation of different rooms or warehouses should be decided depending on the material typology (raw ingredient for food production; raw material for packaging processes; etc.) and the subdivision between different materials into the same typology (examples: chilled storage; 20–25 °C—storage; dry environments, etc.). Clearly, every decision depends mainly on the risk assessment of all possible dangers.

The subdivision of food plants and warehouses in different areas influences the quality and safety of raw and ready-to-eat foods. In detail, good manufacturing practices (GMP) should at least concern the following factors (Santana et al. 2009):

(a) Suitable storage, in terms of the definition and practical implementation of times, temperature, handling and protection for raw ingredients (including additives) with some effect on the quality and safety of the final product(s). This point should also include the separated storage by the type or group, with the use of non-wooden pallets or treated wooden packaging materials such as heat-treated or fumigated objects with methyl bromide (Dwinell 2004; Shahidi 2011; Woodroffe 2010);
(b) Suitable storage of time, temperature, handling and protection against environmental agents (dust, foreign bodies, UV light, heating, excessive humidity, etc.) for packaging materials;
(c) Suitable storage for food-contact materials and objects with regard to food processing machinery (examples: plastic moulds, pliable metallic plates, etc.);
(d) Linear flow of food processing in one direction only, with the aim of avoiding cross-contamination episode between different working lines and related food intermediates;
(e) Suitable storage of hazardous substances for cleaning, sanitising substances and pest control compounds (insecticides, acaricides, etc.);
(f) Suitable and separated storage for food allergens and genetically modified organisms (GMO) foods (Hino 2002; Van der Vorst 2006). Additionally, adequate labelling measures are strictly needed in food industries when speaking of food commodities without clear allergenic or GMO identification (Hino 2002; Trienekens and Zuurbier 2008);
(g) Exposure to electromagnetic fields (or ionisation generator).

When speaking of unpackaged (unprotected) food commodities, the subdivision in different areas such as ‘high risk’ and ‘high care’ zones (Voltmer 2012) should also be based on the assessed risk. As an example, significant *Listeria*-food safety risks can justify the localisation of a detailed high risk or high care zone (Voltmer 2012). Anyway, the ‘high risk’ zone concerns only areas where processed (food) products are unpackaged and/or is still open after a treatment which eradicates or reduces significantly the risk. On the other hand, ‘high care’ zones concern only areas where (food) products need protecting in order to avoid further contamination after a treatment which does not eliminate completely the risk (Voltmer 2012). The correct decision has to be taken on the basis of a ‘production zone decision tree’ (BRC 2012). In addition, ‘low risk’ areas concern zones at room temperature where stored foods are not considered significant ‘culture media’ for the proliferation of pathogens (BRC 2012).

2.4 Segregation of Packaging Materials and Equipments

Food contamination may also occur via food packaging materials and objects. The nature of 'passive microbial contamination' vehicles is known in the scientific literature when speaking of food containers and correlated parts (Brunazzi et al. 2014; Parisi 2012, 2013). However, the problem of microbial spreading in foods may include each potential food-contact surface and material in food plants, warehouses and retail structures. For example, the diffusion of *Listeria* spp. has been extensively studied in different environments where the presence of non-edible surfaces is the common point (Centers for Disease Control and Prevention 2011; Gandhi and Chikindas 2007; Tompkin et al. 1999; Tompkin 2002).

For these reasons, food packaging materials and objects should be adequately stored in separated warehouses, according to the most recent quality standards (Parisi et al. 2009b, c). Adequate sealing and/or protecting procedures for the storage of 'in-use' food-contact materials and objects should be established and fully implemented. In fact, the possible occurrence of peculiar biofilms (microbial agglomerations on plastic polymers or metallic surfaces) cannot be excluded before production. Cleaning and sanitising methods should be sure enough with relation to this risk. On the other hand, the possible occurrence of the formation of proto-biofilm agglomerations during certain cheese productions has highlighted the capability of survival of certain microbial species even under drastic thermal conditions. As a consequence, non-edible food-contact surfaces should be considered as potential vehicles of microbial contamination in different environments (Centers for Disease Control and Prevention 2011).

2.5 Aerosolised Spreading

Another source of cross-contamination between different raw materials, ingredients, working lines and products is always connected with the so-called 'aerosolised' matter. Briefly, every food plant is a sort of 'microcosm'. A number of possible matter transfers can occur at the same time into the same room or between two different (and far) areas, depending on the following factors (Burfoot 2005):

(a) The rate of generation of airborne particles;
(b) Particle dimensions and related speed;
(c) The direction of air flows in a single room;
(d) Exposure areas of food-contact surfaces (including walls and ceilings) and unpackaged/intermediate foods in high care areas;
(e) The peculiar flow of food processing (one direction only should be preferable);
(f) The number of concomitant food processes;
(g) The number of moving machinery parts, including hand trucks, different carriages, fork lifts, etc.;

(h) The number of working operators (blue workers should be always considered as potential contamination vehicles);
(i) The correct procedure for washing in food processing plants (the higher the amount of sprayable water, the higher the potential formation of aerosolised suspensions with or without living microorganisms);
(j) The correct disinfection of cleaning systems;
(k) The air-handling system, natural or forced, the numbers of air diffusors; the speed of threads, the dehumidification/humidification capacity; the source of the air treatment in place;
(l) The maintenance of the filtration system.

In general, aerosols can also occur in closed areas such as chillers and other warehouses. Should this be the situation, the problem could appear simpler because of the 'staticity' of microbial colonies in restricted spaces. Unfortunately, several failures seem to be correlated or originated into restricted zones (Materia et al. 2009), even at low temperature (2 ± 2 °C).

With regard to cleaning tools and their management, it has been recently reported that high-pressure washdown systems may be the cause of aerosolised suspensions with consequent problems of cross-contamination (Parisi et al. 2009b). The same situation may also occur when manual cleaning instruments are not controlled and sanitised (Parisi et al. 2009c). For these reasons, forced ventilation and/or other strategies are needed if a remarkable number of viable particles are detected in food plants (Burfoot 2005). Otherwise, excessive aerosolised suspensions may cause the formation of durable biofilms (*Salmonella* spp., etc.) on food-contact materials and objects in food plants and small rooms such as kitchens (Chmielewski and Frank 2003; Humphrey et al. 1994).

The use of similar techniques in food plants such as dairy industries may be very useful (Gibson et al. 1999). However, several authors recommend considering cautiously collected results 'on ground' in certain situations, depending on the used instruments (Kang and Frank 1990).

In conclusion, the management of the above-discussed factors can be helpful. On the other hand, the prevention of air contamination should be efficacy obtained when forced ventilation systems are used and regularly inspected with the aim of preventing malfunctions and/or possible (and sudden) formation of aerosolised suspensions at some point in flow processes.

Finally, the proper maintenance of the sensors and control units inside the governed climate, especially in confined areas, has to be considered (Brera et al. 2013).

References

Amjad Z (ed) (1993) Reverse osmosis: membrane technology, water chemistry, and industrial applications. Chapman & Hall, International Thomson Publishing, New York

Barbieri G, Barone C, Bhagat A, Caruso G, Conley ZR, Parisi S (eds) (2014a) The problem of the aqueous absorption in processed cheeses. A simulated approach. The influence of chemistry on new foods and traditional products. SpringerBriefs in Chemistry of Foods. Springer, Heidelberg

Barbieri G, Barone C, Bhagat A, Caruso G, Conley ZR, Parisi S (eds) (2014b) Food manufacturing and allergen management. The influence of chemistry on new foods and traditional products. SpringerBriefs in Chemistry of Foods. Springer, Heidelberg (in press)

Bratt L (ed) (2010) Fish canning handbook. Wiley, Oxford. doi:10.1002/9781444323405

BRC (2012) understanding high risk and high care BRC global standard for food safety issue 6. British Retail Consortium (BRC), London. http://brcglobalstandards.com/Portals/0/Books/Understanding_high_risk/highrisk/assets/basic-html/page1.html. Accessed 14 Jan 2015

Brera C, De Santis A, Debegnach B, Gregori F, Pannunzi E, Toscan MCB (2013) Le micotossine nella filiera agroalimentare. In: Proceedings of the fourth National Congress. Rapporti ISTISAN n. 13/18, Istituto Superiore Sanità, Rome

Brunazzi G, Parisi S, Pereno A (2014) Packaging and food: a complex combination. In: Brunazzi G, Parisi S, Pereno A (eds) The importance of packaging design for the chemistry of food products. SpringerBriefs in Chemistry of Foods. Springer, Heidelberg, pp 7–56. doi: 10.1007/978-3-319-08452-7_2

Burfoot D (2005) Aerosols as a contamination risk. In: Lelieveld H, Mostert MA, Holah J (eds) Handbook of hygiene control in the food industry. Woodhead Publishing Ltd, Cambridge, pp 93–102

Casani S, Rouhany M, Knøchel S (2005) A discussion paper on challenges and limitations to water reuse and hygiene in the food industry. Water Res 39(6):1134–1146. doi:10.1016/j.watres.2004.12.015

Centers for Disease Control and Prevention (2011) Multistate outbreak of listeriosis associated with Jensen Farms cantaloupe—United States. Morb Mortal Wkly Rep 60, 39:1357. http://www.cdc.gov/mmwr/preview/mmwrhtml/mm6039a5.htm. Accessed 14 Jan 2015

Chmielewski RAN, Frank JF (2003) Biofilm formation and control in food processing facilities. Compr Rev Food Sci Food Saf 2(1):22–32. doi:10.1111/j.1541-4337.2003.tb00012.x

Codex Alimentarius Commission (2000) Proposed draft guidelines for the hygienic reuse of processing water in food plants, CX/FH 00/8. CODEX Committee on Food Hygiene, Codex Alimentarius Commission, Washington, DC, pp 1–12

Dwinell LD (2004) Mitigating the pine wood nematode and its insect vectors in transported coniferous wood. Nematol Monogr Perspect 2:825–835

Evans JA, Russell SL, James C, Corry JE (2004) Microbial contamination of food refrigeration equipment. J Food Eng 62(3):225–232. doi:10.1016/S0260-8774(03)00235-8

Fenlon DR, Wilson J, Donachie W (1996) The incidence and level of Listeria monocytogenes contamination of food sources at primary production and initial processing. J Appl Bacteriol 81 (6):641–650. doi:10.1111/j.1365-2672.1996.tb03559.x

Food and Drug Administration (1999) Microbiological safety evaluations and recommendations on sprouted seeds. National advisory committee on microbiological criteria for foods. Int J Food Microbiol 52(3):123–153

Gandhi M, Chikindas ML (2007) Listeria: a foodborne pathogen that knows how to survive. Int J Food Microbiol 113(1):1–15. doi:10.1016/j.ijfoodmicro.2006.07.008

Gibson H, Taylor JH, Hall KE, Holah JT (1999) Effectiveness of cleaning techniques used in the food industry in terms of the removal of bacterial biofilms. J Appl Microbiol 87(1):41–48. doi:10.1046/j.1365-2672.1999.00790.x

Gil MI, Selma MV, López-Gálvez F, Allende A (2009) Fresh-cut product sanitation and wash water disinfection: problems and solutions. Int J Food Microbiol 134(1):37–45. doi:10.1016/j.ijfoodmicro.2009.05.021

Gupta BS, Ako JE (2005) Application of guar gum as a flocculant aid in food processing and potable water treatment. Eur Food Res Technol 221(6):746–751. doi:10.1007/s00217-005-0056-4

Gurnari G (2006) Analisi e valutazione dei rischi igienici e dei punti critici per la sicurezza dei prodotti alimentari. Paper presented at the Congress 'La filiera di produzione dei principali alimenti', Salsomaggiore Terme

Hino A (2002) Safety assessment and public concerns for genetically modified food products: the Japanese experience. Toxicol Pathol 30(1):126–128. doi:10.1080/01926230252824815

Huang YR, Hung YC, Hsu SY, Huang YW, Hwang DF (2008) Application of electrolyzed water in the food industry. Food Control 19(4):329–345. doi:10.1016/j.foodcont.2007.08.012

Humphrey TJ, Martin KW, Whitehead A (1994) Contamination of hands and work surfaces with Salmonella enteritidis PT4 during the preparation of egg dishes. Epidemiol Infect 113(3):403–409. doi:10.1017/S0950268800068412

Kamble SP, Jagtap S, Labhsetwar NK, Thakare D, Godfrey S, Devotta S, Rayalu SS (2007) Defluoridation of drinking water using chitin, chitosan and lanthanum-modified chitosan. Chem Eng J 129(1):173–180. doi:10.1016/j.cej.2006.10.032

Kang YJ, Frank JF (1990) Characteristics of biological aerosols in dairy processing plants. J Dairy Sci 73(3):621–626. doi:10.3168/jds.S0022-0302(90)78712-7

Kirby RM, Bartram J, Carr R (2003) Water in food production and processing: quantity and quality concerns. Food Control 14(5):283–299. doi:10.1016/S0956-7135(02)00090-7

Materia I, Parisi S, Micali M, Mauro A, Delia S, Laganà P (2009) Valutazione dello spreading microbico nelle industrie casearie. Ricostruzione della diffusione dei Coliformi tramite aerosol nelle celle frigo non ventilate. Ig San Pubbl 5, Supplemento:391

Montanari F, Jezsó V, Donati C (2015) Risk regulation in non-animal food imports. The European Union approach. SpringerBriefs in Chemistry of Foods. Springer, Heidelberg (in press)

Ölmez H, Kretzschmar U (2009) Potential alternative disinfection methods for organic fresh-cut industry for minimizing water consumption and environmental impact. LWT Food Sci Technol 42:686–693. doi:10.1016/j.lwt.2008.08.001

Onsosyen E, Skaugrud O (1990) Metal recovery using chitosan. J Chem Technol Biotechnol 49 (4):395–404. doi:10.1002/jctb.280490410

Parisi S (2002) La stesura del Piano di Autocontrollo nel comparto agro-alimentare. Il Chimico Italiano XIII, 2:25: 28

Parisi S (2012) Food packaging and food alterations. The user-oriented approach. Smithers Rapra Technology Ltd, Shawbury, Shropshire

Parisi S (2013) Food industry and packaging materials. User-oriented guidelines for users. Smithers Rapra Technology Ltd, Shawbury

Parisi S, Delia S, Laganà P (2009a) Possible connections between Food Packaging and Microbiological Spreading. World Food Reg Rev 19(5):15–17

Parisi S, Delia S, Laganà P (2009b) Possible connections between food packaging and microbiological spreading. Part 2. World Food Reg Rev 19(6):9–21

Parisi S, Delia S, Laganà P (2009c) Possible connections between food packaging and microbiological spreading. Part 3. World Food Reg Rev 19(7):19–21

Pisanello D (2014) Chemistry of foods: EU legal and regulatory approaches. SpringerBriefs in Chemistry of Foods. Springer, Heidelberg

Poretti M (1990) Quality control of water as raw material in the food industry. Food Control 1 (2):79–83. doi:10.1016/0956-7135(90)90089-U

Santana NG, Almeida RC, Ferreira JS, Almeida PF (2009) Microbiological quality and safety of meals served to children and adoption of good manufacturing practices in public school catering in Brazil. Food Control 20(3):255–261. doi:10.1016/j.foodcont.2008.05.004

Scott E, Bloomfield SF (1990) The survival and transfer of microbial contamination via cloths, hands and utensils. J Appl Bacteriol 68(3):271–278. doi:10.1111/j.1365-2672.1990.tb02574.x

Spica VR, Bonadonna L, Fantuzzi G, Liguori G, Vitali M, Gurnari G, Pedullà S (2012) Sicurezza dell'acqua negli edifici. Traduzione italiana. Rapporti ISTISAN 2012 12/47. Istituto Superiore di Sanità, Rome. http://apps.who.int/iris/bitstream/10665/76145/7/9789241548106_ita.pdf. Accessed 26 Jan 2015

Shahidi F, Arachchi JKV, Jeon YJ (1999) Food applications of chitin and chitosans. Trends Food Sci Technol 10(2):37–51. doi:10.1016/S0924-2244(99)00017-5

Shahidi SSM (2011) Comparison of the potential environmental impacts of microwave phytosanitary treatment of wooden pallets to conventional heat and methyl bromide treatments. Dissertation, The Pennsylvania State University

Stilo A, Parisi S, Delia S, Anastasi F, Bruno G, Laganà P (2009) Food security in Europe: comparison between the “Hygiene Package” and the British Retail Consortium (BRC) & International Food Standard (IFS) protocols. Ann Ig 21(4):387–401

Tompkin RB (2002) Control of Listeria monocytogenes in the food-processing environment. J Food Prot 65(4):709–725

Tompkin RB, Scott VN, Bernard DT, Sveum WH, Gombas KS (1999) Guidelines to prevent post-processing contamination from Listeria monocytogenes. Dairy Food Env Sanit 19:551–603

Trienekens J, Zuurbier P (2008) Quality and safety standards in the food industry, developments and challenges. Int J Prod Econ 113(1):107–122. doi:10.1016/j.ijpe.2007.02.050

Van der Vorst JG (2006) Product traceability in food-supply chains. Accred Qual Assur 11(1, 2):33–37. doi:10.1007/s00769-005-0028-1

Voltmer E (2012) News and trends of food safety standards, Belgrad. http://www.kombeg.org.rs/Slike/CeObrazovanje/2012/III%20FORUM%20KVALITETA/2%20Elisabeth%20Voltmer%20News%20and%20Trends.pdf. Accessed 14 Jan 2015

Wagenaar JA, Jacobs-Reitsma W, Hofshagen M, Newell D (2008) Poultry colonization with Campylobacter and its control at the primary production level. In: Nachamkin I, Szymanski CM, Blaser MJ (eds) Campylobacter, 3rd edn. American Society for Microbiology, Washington, DC, pp 667–678

Woodroffe N (2010) Analysis of ISPM 15 and its impact on the wood pallet industry. Drake J Agric L 15:199–221

World Health Organization (1996) Guidelines for drinking-water quality, 2nd edn. vol 2, Health Criteria and Other Supporting Information. World Health Organization, Geneva. http://www.who.int/water_sanitation_health/dwq/2edvol2p1.pdf. Accessed 14 Jan 2015

Xie W, Xu P, Wang W, Liu Q (2002) Preparation and antibacterial activity of a water-soluble chitosan derivative. Carbohydr Polym 50(1):35–40. doi:10.1016/S0144-8617(01)00370-8

Chapter 3
Hygiene of Food-Contact Approved Materials for Machinery

Abstract Food contamination may occur via different channels, including food containers and food-contact approved packaging materials. Substantially, the problem of microbial spreading in foods may include each potential food-contact surface in the food chain. One of the most known and studied causes of microbial contamination is the formation of microbial agglomerations on food-contact surfaces or biofilms. For this reason, storage and sealing procedures have the same importance of cleaning and sanitising methods, on the basis of adequate Hazard Analysis and Critical Control Point (HACCP) studies. Recently, the possible formation of protobiofilm agglomerations during certain cheese productions has been discussed. Another problem is the possible occurrence of aerosolised suspensions in food production areas, including chillers and warehouses, and dimensionally limited and environmentally insulated areas such as supermarkets, hypermarkets and shopping centres. Finally, the importance of hygienic design (food processing equipment, production areas, etc.) should be always highlighted. These arguments are briefly discussed in this chapter on the basis of the correlated importance in the HACCP ambit.

Keywords CIP system · Cleaning · Food contamination · Good manufacturing practice · HACCP · Sanitisation

3.1 Food-Contact Materials and Machinery: An Overview

In general, food contamination may occur via different channels, including food packaging materials and objects (Brunazzi et al. 2014; Parisi 2012, 2013). This statement is particularly true when speaking of microbial contamination: the nature of ‘passive microbial contamination’ vehicles is known in the scientific literature when speaking of food containers and correlated parts (Caruso and Parisi 2013; Italian Institute of Packaging 2013; Parisi 2011; Caruso and Parisi 2013; Parisi et al. 2009a, b, c). However, the problem of microbial spreading in foods may include

G. Gurnari, *Safety Protocols in the Food Industry and Emerging Concerns*,
Chemistry of Foods, DOI 10.1007/978-3-319-16492-2_3

each potential food-contact surface and material in food plants, warehouses and retail structures (Faille et al. 2002; Gounadaki et al. 2008; Grob et al. 2006; Jun et al. 2010).

Most recent quality standards—two examples are the Global Standard for Food Safety, issue 6, and the International Featured Standard Food, version 6—require that food packaging materials and objects are adequately stored in separated warehouses. Actually, this requirement was already considered several years ago with other possible measures against microbial contamination (Stilo et al. 2009).

With reference to the microbiological risk in food production and packaging plants, the possible occurrence of peculiar biofilms (microbial agglomerations on plastic or metallic surfaces) cannot be excluded. As a consequence, storage and sealing procedures for food-contact surfaces have the same importance of cleaning and sanitising methods, on the basis of adequate Hazard Analysis and Critical Control Point (HACCP) studies and the correlated risk assessment (Parisi 2002). From the hygienic viewpoint, another possible emergency may be correlated to the possible formation of protobiofilm agglomerations during certain productions. With regard to cheeses, the capability of survival of certain microbial species even under drastic thermal conditions has been recently studied (Parisi 2002, 2010; Parisi et al. 2009a, b, c). Non-edible food-contact surfaces should be considered as potential vehicles of microbial contamination in different environments (Centers for Disease Control and Prevention 2011).

Finally, the problem of aerosolised suspensions in food companies, warehouses and other locations where foods may be distributed should be discussed. Many factors may have their own ‘weight’ when speaking of biologic and chemical aerosols in dimensionally limited and environmentally insulated areas such as supermarkets, hypermarkets (Barrabeig et al. 2010; Wierzbicka et al. 2009) and shopping centres (Lee et al. 2012; Nunes et al. 2005), including also

- Exposure areas of food-contact surfaces (including walls and ceilings) and unpackaged/intermediate foods in high care areas;
- The peculiar flow of food processing (one direction only should be preferable);
- The number of moving machinery parts, including hand trucks, different carriages, fork lifts, etc.;
- The number of working operators (blue workers should be always considered as moving food-contact surfaces);
- The correct procedure of washing in food processing plants (the higher the amount of sprayable water, the higher the potential formation of aerosolised suspensions with or without living microorganisms).

Because of the variety of possible arguments about the connection (cause and effect) between food-contact surfaces and microbial spreading in food products, a few factors have been discussed here on the basis of the correlated importance in the HACCP ambit (Mantovani et al. 2012).

3.2 Chemical Features of Suitable Food-Contact Surfaces

Basically, food-contact surfaces—plastics, paper and board materials, rubber, metals, etc.—are a thorny argument because of the wide spectrum of possible uses. It can be affirmed that two categories of food-contact applications are considered in the ambit of food safety and hygiene:

(a) Approved materials for preserving and packaging foods and food intermediates: containers and correlated parts;
(b) Approved materials used in processing equipment or machinery. This group includes removable moulds and containers for temporary transport within food processing/packaging industries.

Based on the regulatory viewpoint, the European Union (EU) approach should be considered as a useful example (Montanari et al. 2015; Pisanello 2014): the matter is generally regulated by the Framework Regulation (EC) No 1935/2004 (European Parliament and Council 2004), with the exclusion of fixed public or private water supply equipment. In addition, these materials have to be manufactured in compliance with the so-called ‘Good Manufacturing Practice’ for materials and articles intended to come in contact with foods, in accordance with the Reg. (EC) No 2023/2006 (European Commission 2006). Specific classes of food-contact materials are ruled in the European Union (EU) by other regulatory documents—plastics, regenerated cellulose films, ceramics, and recycled plastics, ‘smart’ (active and intelligent) materials (Parisi 2009; Pisanello 2014).

Interestingly, the Reg. (EC) No 2023/2006 has introduced new concepts (European Commission 2006) with regard to the definition of food-contact materials (Art. 3):

(1) ‘Good manufacturing practice’ (GMP). This point concerns the importance of quality assurance of materials without dangerous effects on human health and the ability of modifying the composition or causing a deterioration of foods in an unacceptable way.
(2) ‘Quality assurance system’. The Reg. (EC) No 2023/2006 requires that GMP cannot exist without a fully implemented management system which can give evidence of the compliance of food packaging materials with the existing legislation. The ‘intended use’ of these articles is explicitly cited.
(3) ‘Quality control system’. This system is absolutely needed when speaking of efficient quality management or assurance services.
(4) ‘Non-food-contact side’. This definition concerns the surface of the material or article that is not directly in contact with food. It should be noted that the existence of a non-food-contact is correlated to the intended use(s) of food packaging materials when a peculiar compound has two different sides.
(5) ‘Food-contact side’. Differently from the previous point, this definition concerns explicitly the intended and permanent or temporary contact between the surface of a material or article and foods.

Fig. 3.1 The chemical composition of food-contact materials may offer several contamination possibilities, including microbial contamination. Basically, food-contact surfaces are correlated to containers and objects for processing equipments such as washing machinery for fresh vegetables

Existing European legislations aim to avoid explicitly the chemical migration of peculiar and undesired (or dangerous) substances from food packaging materials to foods. On the other side, the chemical composition of these materials may offer other contamination possibilities, including microbial contamination. For this reason, a brief classification of the most known and used food-contact materials for industrial applications would be useful. Because of the basic aim of this book, the discussion is limited to food-contact materials for processing equipments and machinery (Fig. 3.1), with the complete exclusion of food containers (Italian Institute of Packaging 2013).

At present, the basic components for the construction and realisation of the approved food-contact processing equipment are listed as follows (Lewan and Partington 2014; Muncke 2014; Parisi 2012; Singh 2011):

(1) Plastic materials: high-density polyethylene, polypropylene, polyamide (nylon), unplasticised polyvinylchloride, melamine-formaldehyde resins, polycarbonate, acetal copolymer, chlorinated polyvinyl chloride (Fig. 3.2), polyethylene terephthalate, etc.;
(2) Elastomers: rubbers such as ethylene-propylene terpolymers, nitrile and acrylonitrile-butadiene materials, silicon rubbers, fluoroelastomers;
(3) Metal supports: stainless steel (Fig. 3.2), ‘inconel’ (a nickel-chromium alloy), mild steel/iron (for dry ingredients and syrups), titanium;

Fig. 3.2 Corrosion damages on different materials for food processing systems. Stainless steel is widely used; on the other hand, corrosion processes can be notably reduced by means of plastic materials such as chlorinated polyvinyl chloride (C-PVC)

(4) Additional supports for food-contact surfaces: fasteners, adhesives (for keeping gaskets), etc.;
(5) Additional materials for non-food-contact surfaces: food-grade lubricants, caulking compounds such as silicone;
(6) Glass, fibre glass, crystal;
(7) Ceramics, pottery, porcelain, glazed lithoid.

Several remarks may be made with reference to the above-mentioned materials. In regard to stainless steels, types AISI 304 and 316 are the most preferable choices, including low-carbon versions. Another important note concerns the use of polytetrafluoroethylene because of its porosity; in addition, this polymer is not easily cleanable and should not be recommended for permanently tight seals and aseptic packaging systems (Lewan and Partington 2014).

As regards elastomers, it should be remembered that ethylene-propylene terpolymers are not suitable for the production of foods containing oils or fat molecules. These materials are not oil and fat resistant (Lewan and Partington 2014). On the other hand, silicon rubbers and fluoroelastomers are considered resistant for high-temperature processes (Lewan and Partington 2014).

Generally, these materials are used for the production of equipment such as (Sousa et al. 2014; Muncke 2014):

- Children’s tableware;
- Complex packaging machines (e.g.: thermosealing systems for under-vacuum plastic bags);

Heat exchangers

Fig. 3.3 Heat exchangers for industrial applications are composed of heat transfer parts and fluid distribution elements (Shah and Sekulic 2003). Generally, used materials include stainless steel and plastic compounds. These items can be a source of chemical contamination; microbiological contamination is also possible. In addition, the occurrence of similar pieces in food products is defined as physical contamination

- Conveyor belts;
- Cutting (chopping) boards;
- Fermenters (also called bioreactors);
- Evaporators;
- Electric insect traps;
- General cookware (cooking and serving spoons, etc.);
- Heat exchangers (Fig. 3.3);
- Knives;
- In-plant trucks (stainless steel, galvanised metal if regularly inspected and re-galvanised when necessary);
- Latex single-use gloves;
- Magnetic traps;
- Metallic trays;
- Ovens;
- Plastic cases;
- Plastic baskets;
- Plastic covers;
- Packaging tanks
- Plastic trays;
- Pumps, valves, centrifuges;

- Refillable water bottles;
- Removable aluminium coils and foils;
- Rubber gaskets, hoses and caps;
- Screens and filters;
- Smokehouses;
- Stainless steel sorting and packaging tables;
- Stainless skinning machines;
- Spray dyers.

All the above items can be sources of chemical contamination (Muncke 2014); microbiological contamination is also possible. In addition, the occurrence of similar pieces in food products is defined as physical contamination: non-destructive controls have to be considered (Fig. 3.4). For the first reason, similar materials are included in the EU and the United States of America (USA) regulatory dispositions (Muncke 2014). Interestingly, basic features of 'clean-in-place'—also called CIP—systems depend on the type of food-contact materials to be cleaned and sanitised. For this reason, a basic but reliable guideline about the main features of food-contact materials may be defined on these bases. Because of the necessity for cleaning and sanitising each food-contact surface for food processing application, it may be inferred (Chisti 1999; Singh 2011) that:

(a) Products' contact surfaces should be durable, non-porous, non-adsorbent and nontoxic, easily accessible for cleaning and inspections;
(b) These items should be designed with the aim of avoiding microbial accumulation and the consequent growth.

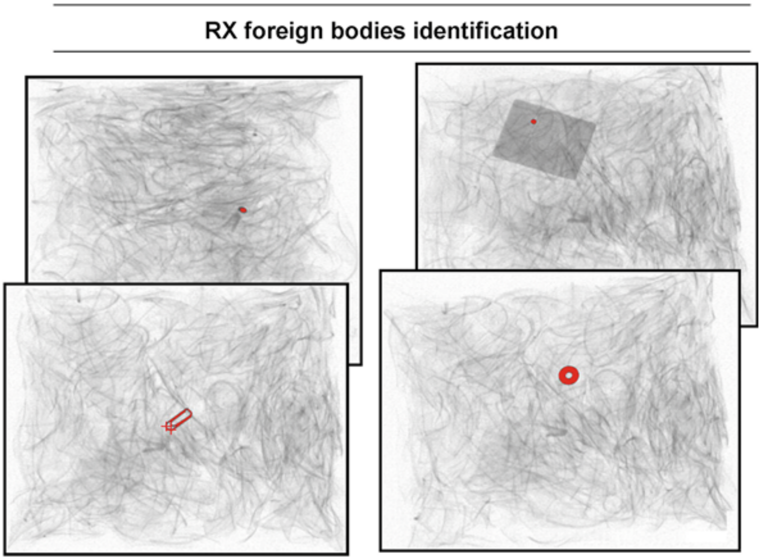


Fig. 3.4 Examples of detection of foreign bodies in food products by means of non-destructive systems

The problem of microbial hazards is directly connected with the above-mentioned features.

On the other hand, the following materials are not suitable or recommended for food-contact applications (Lewan and Partington 2014; Stanfield 2003):

- Cadmium, antimony, lead (except for a maximum amount of 5 %), aluminium (it is not suitable for corrosive products such as moist and liquid applications);
- Enamelware, porcelain;
- Wooden materials;
- Glassware;
- Copper, bronze, brass (the last material may be used in potable water systems and direct contact with brine except for recirculated brine or other solutions);
- Leather and fabric.

3.3 Microbial Biofilms on Approved Food-Contact Surfaces

Currently, much data and research are available for evaluation of microbial accumulations on food-contact surfaces. The available studies are on food-contact packaging materials and objects for packaging and processing purposes (Caruso and Parisi 2013; Parisi et al. 2009a, b, c). However, the main problem in food plants is the reliable and prompt localisation of microbial contamination sources. Thus, it can be assumed that microbial accumulation should be investigated on food-contact equipment and machinery with special attention.

According to several researchers, the efficacy of sanitising procedures seems be reduced or limited by biofilms (Gil et al. 2009). In general, the term ‘biofilm’ is used for communities of microorganisms, different from planktonic cells, which are strongly attached to a surface (Mah and O’Toole 2001). This peculiar attitude is considered one of the main causes for sanitising failures on food-contact surfaces in food industries because of the placement of these microorganisms onto inaccessible surfaces of irregular shape, including cut surfaces and cracks (Burnett et al. 2000; Gil et al. 2009; Ölmez and Kretzschmar 2009; Parish et al. 2003; Takeuchi and Frank 2000).

Interestingly, the formation of biofilms on food-contact surfaces is not similar to chaotic and randomised accumulations of single or mixed microbial species. On the contrary, recent researches have highlighted that the final ‘biofilm’ should be considered as one of the main steps in a biological lifecycle (initiation, maturation, maintenance, development and dissolution) after initial development in response to the bioavailability of nutrient substances (Gil et al. 2009). As a result, the formation of stable and multiple microbial accumulations on food-contact surfaces for food processing applications should be predictable and probable in certain environments. This reflection is true even when cleaning and sanitising procedures are carefully designed, continually implemented and regularly re-evaluated. Many factors may potentially influence the metastable food environment of food plants (Parisi 2002), from the probable diversification of raw materials (edible ingredients) to the modification of seasonal parameters (relative humidity, sunlight, temperature, etc.).

Should a single or mixed microbial accumulation be able to strongly adhere on a surface with adequate nutrient bioavailability and other favourable conditions, one of the next steps would be presumably the synthesis of large amounts of exopolysaccharides with protection functions (O'Toole et al. 2000). Interestingly, biocide resistance has been observed for different biofilms: this behaviour has been often reported to be mainly dependent on the quantity of synthesized exopolysaccharides (Boyd and Chakrabarty 1995; Gacesa 1998). With regard to a simple *Pseudomonas aeruginosa* biofilm, one of the studied structures appears as a sort of mushroom-shaped three-dimensional network surrounded by an extracellular polysaccharide layer. On the other hand, different multiple populations might form different structures, but the presence of protective hydrated polysaccharide matrices appears often observed (Sutherland 2001). Exopolysaccharide layers may contribute directly to many specific properties of biofilms such as: aqueous absorption, mechanical stability, formation of rigid gel structures, prevention of lethal desiccation against diurnal variations inside matrices by means of the highly hydrated and external layer, rooting, etc. (Sutherland 2001).

From the microbiological viewpoint, the presence of Gram-negative bacteria—*P. aeruginosa, P. fluorescens, Escherichia coli, Vibrio cholera*—is important in food industries because of their reducing role and the probable prevalence in foods with adequate (negative) redox potentials (Delia et al. 2005). On the other hand, Gram-positive bacteria are also able to form stable and remarkable biofilm accumulations: useful examples in food environments include *Staphylococcus epidermidis, S. aureus, Enterococcus* spp., etc. (Abee et al. 2011; Sharma and Anand 2002; Yazdankhah et al. 2006).

In many of these cases the proximity or contact with electric or electromagnetic fields causes an increase in defence, both in unicellular and multicellular organisms, favoring rapid evolutionary processes (as the most rapid absorption of phosphorus).

3.4 Eradication of Microbial Biofilms

Substantially, the eradication of microbial contamination by biofilms should be obtained with the improvement in cleaning and sanitising procedures. This reflection is always repeated when speaking of HACCP strategies. For example, practical guidelines for preventing food recontamination by *Listeria monocytogenes* should include regular controls on food-contact surfaces with the aim of avoiding the establishment and growth of this dangerous microorganism in small and inaccessible niches (Tompkin et al. 1999). The disassemblement of food processing and packaging plants should be recommended. In addition, every possible and visible damage (including stains or toning) on machinery and other equipment should be monitored and repaired or replaced as soon as possible (Tompkin et al. 1999).

The importance of hygienic design should be highlighted: the use of machines and/or separated parts that are difficult to clean and sanitise is not recommended. One of the most known and debated situations is surely conveyor belts because of their particular function in food processing plants, their peculiar shape and the (possible) proximity to the floor. Conveyor belts may be sources of pathogens and degrading microorganisms (Chmielewski and Frank 2003; Lundén et al. 2002; Tompkin 2002; Tompkin et al. 1999). Other examples are contaminated racks: adequate heat treatments such as sterilisation are recommended for sanitation purposes (Fu et al. 1995; Himelbloom et al. 2007; Jacob 1989).

With regard to cleaning and sanitising procedures, it has to be considered that adequate protocols depend on the particular type or types of microorganisms. For example, the use of quaternary ammonium compounds as sanitising agents has been found effective against *L. monocytogenes*; in addition, the recontamination on sanitised food surfaces appear inhibited because of a residual germicide power (Lundén et al. 2002). At the same time, *Listeria* biofilms may be contrasted with liquid solutions containing peracetic and peroctanoic acids (Lundén et al. 2002). On the other hand, similar systems may fail in several situations. For instance, it has been recently reported that the concomitant use of sodium dichloroisocyanurate, peracetic acid and hydrogen peroxide may not be efficient on *S. aureus* biofilms (supports: glass and stainless steel), in spite of the notable performance of peracetic acid and hydrogen peroxide (Marques et al. 2007). In addition, the combined use of acidic electrolysed water and sodium hypochlorite (NaOCl) solution may be considered effective compared with traditional NaOCl solution with regard to *S. aureus* and *E. coli* contamination (Issa-Zacharia et al. 2010). In fact, biofilm—*S. aureus* populations are reported to be more tolerant than other undesired bacteria such as *E. coli* and *Salmonella enteritidis* in certain conditions, when NaOCl is used, while other solutions (alkyldiaminoethyl glycine hydrochloride, benzalkonium chloride polyhexamethylene biguanide, etc.) are used (Ueda and Kuwabara 2007).

Moreover, the location of possible contamination and harbour sites for biofilms is always important. In general, dangerous bacteria such as *L. monocytogenes* may be found on the surface of general equipment and on other materials, including (Tompkin et al. 1999):

- Damaged (cracked) walls
- Ceilings
- Catwalks
- Floors
- Trolleys
- Forklifts
- Cleaning tools (sponges, floor scrubbers, etc.)
- Conveyor belts, especially in those made of porous or fibrous materials the final sanitisation may be very helpful (Fig. 3.5)
- Hollow rollers for conveyors
- Trash cans
- Motor housings

Fig. 3.5 Conveyor belts may be easily contaminated by microorganisms, especially when porous or fibrous materials have been used in their construction. The final sanitisation may be very helpful

- Ice makers
- Damaged (cracked) hoses
- Condensate drip pans
- Coolers
- Spiral freezers
- Fan devices
- Hydraulic pumps
- Heat pumps/exchangers
- Vacuum pumps.

With regard to other agents such as *Salmonella* spp. and other spoilage bacteria, the sanitisation of structures such as dry milling and processing environments for flour and dry mixtures is highly recommended (International Commission on Microbiological Specifications for Foods 2011). On the other hand, *S. aureus* may pose additional problems as one of the possibilities (Giordano et al. 2012; Nema et al. 2007) of different causes including food workers and handlers in food industries.

3.5 Unexpected Complications: Protobiofilms

The correct management of cleaning and sanitising procedures may allow food technologists and production managers to reduce microbial contamination episodes in food products and environments. For example, clean-in-place systems are extensively used and are well known as one of the most powerful instruments against the residual presence of pathogen and spoilage microorganisms on food-contact surfaces.

However, the punctual and precise localisation of microbial agglomerations, also called biofilms, on non-edible surfaces such as plastic or metallic supports for food processing applications remains one of the most difficult challenges in the modern industry, in spite of recent results (Bénézech et al. 2002). For example, the formation of biofilms in beer processing plants may remain ‘hidden’ if initial agglomerates are localised on ‘dead’ machinery areas such as screws: these zones may not be directly exposed to cleaning procedures.

Other recent studies have also revealed the possible production of microbial aggregations in food processing plants during production. In particular, the existence of small but persistent amount of living colonies—coliform bacteria—on polytetrafluoroethylene surfaces during the production of *pasta filata* cheeses has been investigated in function of processing times (Parisi 2010). The obtained results highlight the role of these coliform bacteria during high-temperature ‘washing’ treatment of cow milk curds. In detail, coliform counts appear to slightly increase during production in spite of the well-known sensibility of these microorganisms to temperatures ≥55–60 °C. As a consequence, the hypothesis of possible microbial agglomerations has been proposed in ‘hidden’ sections of cheese processing plants: these ‘protobiofilm’ structures should be able to survive (Parisi 2010) because of the thermal protection of fatty molecules after phase separation from hot-washed cow milk curds (water temperature: 80 °C).

This research is not correlated with the general problem of biofilms. In fact, the possible agglomeration of coliform bacteria in small but enduring and living protobiofilm matrices should be favoured by the persistent accumulation of fatty molecules into ‘dead’ zones of food processing plants. In addition, there is no evidence of exopolysaccharides structure or similar networks (Parisi 2010). However, the cited study shows the importance of the design in the construction of food machinery. In this situation, proposed protobiofilms (during food processing) and biofilms (after cleaning and sanitising procedures) should be substantially located in the same place.

References

Abee T, Kovács ÁT, Kuipers OP, Van der Veen S (2011) Biofilm formation and dispersal in Gram-positive bacteria. Curr Opin Biotechnol 22(2):172–179. doi:10.1016/j.copbio.2010.10.016

Barrabeig I, Rovira A, Garcia M, Oliva JM, Vilamala A, Ferrer MD, Sabrià M, Domínguez A (2010) Outbreak of Legionnaires’ disease associated with a supermarket mist machine. Epidemiol Infect 138(12):1823–1828. doi:10.1017/S0950268810000841

Bénézech T, Lelièvre C, Membré JM, Viet AF, Faille C (2002) A new test method for in-place cleanability of food processing equipment. J Food Eng 54(1):7–15. doi:10.1016/S0260-8774(01)00171-6

Boyd A, Chakrabarty AM (1995) Pseudomonas aeruginosa biofilms: role of the alginate exopolysaccharide. J Ind Microbiol 15:162–168. doi:10.1007/BF01569821

Brunazzi G, Parisi S, Pereno A (2014) Packaging and food: a complex combination. In: Brunazzi G, Parisi S, Pereno A (eds) The importance of packaging design for the chemistry of food products. SpringerBriefs in Chemistry of Foods. Springer, Heidelberg, pp 7–56. doi:10.1007/978-3-319-08452-7_2

Burnett SL, Chen J, Beuchat LR (2000) Attachment of Escherichia coli O157:H7 to the surfaces and internal structures of apples as detected by confocal scanning laser microscopy. Appl Env Microbiol 66:4679–4687. doi:10.1128/AEM.66.11.4679-4687.2000

Caruso G, Parisi S (2013) Microbial spreading in processed cheeses. Impact of contaminated food packaging materials. Food Packag Bull 22(10): 8–13

Centers for Disease Control and Prevention (2011) Multistate outbreak of listeriosis associated with Jensen Farms cantaloupe—United States, August–September 2011. Morb Mortal Wkly Rep 60 (39):1357. http://www.cdc.gov/mmwr/preview/mmwrhtml/mm6039a5.htm. Accessed 14 Jan 2015

Chisti Y (1999) Modern systems of plant cleaning. In: Robinson R, Batt C, Patel P (eds) Encyclopedia of food microbiology. Academic Press, London, pp 1806–1815

Chmielewski RAN, Frank JF (2003) Biofilm formation and control in food processing facilities. Compr Rev Food Sci Food Saf 2(1):22–32. doi:10.1111/j.1541-4337.2003.tb00012.x

Delia S, Laganà P, Parisi S (2005) Materiali e metodi di confezionamento nella conservazione dei prodotti alimentari refrigerati. In: Proceedings of the XIV national conference “Microbiologia degli alimenti conservati in stato di refrigerazione”, Bologna, University of Bologna, Faculty of Industrial Chemistry, pp 93–111

European Commission (2006) Commission Regulation (EC) No 2023/2006 of 22 December 2006 on good manufacturing practice for materials and articles intended to come into contact with food. Off J Eur Union L384:75–78

European Parliament and Council (2004) Regulation (EC) No 1935/2004 of the European Parliament and of the Council of 27 October 2004 on materials and articles intended to come into contact with food and repealing Directives 80/590/EEC and 89/109/EEC. Off J Eur Union L338:4–17

Faille C, Jullien C, Fontaine F, Bellon-Fontaine MN, Slomianny C, Benezech T (2002) Adhesion of Bacillus spores and Escherichia coli cells to inert surfaces: role of surface hydrophobicity. Can J Microbiol 48(8):728–738. doi:10.1139/w02-063

Fu AH, Sebranek JG, Murano EA (1995) Survival of Listeria monocytogenes and Salmonella typhimurium and quality attributes of cooked pork chops and cured ham after irradiation. J Food Sci 60(5):1001–1005. doi:10.1111/j.1365-2621.1995.tb06279.x

Gacesa P (1998) Bacterial alginate biosynthesis: recent progress and future prospects. Microbiol 144:1133–1143. doi:10.1099/00221287-144-5-1133

Gil MI, Selma MV, López-Gálvez F, Allende A (2009) Fresh-cut product sanitation and wash water disinfection: problems and solutions. Int J Food Microbiol 134(1):37–45. doi:10.1016/j.ijfoodmicro.2009.05.021

Giordano R, Sorbo A, Patriarca V, Ciaralli L (2012) Report of the 14th proficiency testing on meat, milk and fish of the EU Reference Laboratory for chemical elements in food of animal origin. Rapporti ISTISAN n. 12/56, Istituto Superiore di Sanità, Rome. http://www.iss.it/binary/publ/cont/12_56_web.pdf. Accessed 26 Jan 2015

Gounadaki AS, Skandamis PN, Drosinos EH, Nychas GJE (2008) Microbial ecology of food contact surfaces and products of small-scale facilities producing traditional sausages. Food Microbiol 25(2):313–323. doi:10.1016/j.fm.2007.10.001

Grob K, Biedermann M, Scherbaum E, Roth M, Rieger K (2006) Food contamination with organic materials in perspective: packaging materials as the largest and least controlled source? A view focusing on the European situation. Crit Rev Food Sci Nutr 46(7):529–535. doi:10.1080/10408390500295490

Himelbloom BH, Crapo C, Shetty TS, Vorholt C (2007) Pellicle formation and inactivation of Listeria and Staphylococcus species in hot-smoking of salmon. In: Kramer DE, Brown L (eds) International smoked seafood conference workshop proceedings, Anchorage, 5–7 March 2007, pp 27–33. Alaska Sea Grant College Program and the University of Alaska Fairbanks. http://nsgl.gso.uri.edu/aku/akuw07001.pdf#page=33. Accessed 15 Jan 2015

International Commission on Microbiological Specifications for Foods (2011) Microorganisms in foods 8: use of data for assessing process control and product acceptance. Springer Science & Business Media, New York, pp 209–225

Issa-Zacharia A, Kamitani Y, Morita K, Iwasaki K (2010) Sanitization potency of slightly acidic electrolyzed water against pure cultures of Escherichia coli and Staphylococcus aureus, in comparison with that of other food sanitizers. Food Control 21(5):740–745. doi:10.1016/j.foodcont.2009.11.002

Italian Institute of Packaging (2013) Linee guida per la valutazione dell'idoneità al contatto con alimenti del packaging realizzato con materiale proveniente da riciclo. Istituto Italiano Imballaggio, Milan

Jacob M (1989) Safe food handling: a training guide for managers in food service establishments. World Health Organization, Geneva. http://apps.who.int/iris/bitstream/10665/36870/1/9241542454_eng.pdf?ua=1. Accessed 15 Jan 2015

Jun W, Kim MS, Cho BK, Millner PD, Chao K, Chan DE (2010) Microbial biofilm detection on food contact surfaces by macro-scale fluorescence imaging. J Food Eng 99(3):314–322. doi:10.1016/j.jfoodeng.2010.03.005

Lundén JM, Autio TJ, Korkeala HJ (2002) Transfer of persistent Listeria monocytogenes contamination between food-processing plants associated with a dicing machine. J Food Prot 65(7):1129–1133

Lee BU, Hong IG, Lee DH, Chong ES, Jung JH, Lee JH, Kim HJ, Lee IS (2012) Bacterial bioaerosol concentrations in public restroom environments. Aerosol Air Qual Res 12:251–255. doi:10.4209/aaqr.2011.07.0097

Lewan M, Partington E (2014) Food processing equipment construction materials. In: Lelieveld H, Holah JT, Napper D (eds) Hygiene in food processing: principles and practice, 2nd edn. Woodhead Publishing Ltd, Cambridge

Mah TFC, O'Toole GA (2001) Mechanisms of biofilm resistance to antimicrobial agents. Trends Microbiol 9(1):34–39. doi:10.1016/S0966-842X(00)01913-2

Mantovani A, Baldi F, Frazzoli C, Lorenzetti S, Maranghi F (2012) Modelli per la valutazione del rischio/beneficio in sicurezza alimentare. Rapporto ISTISAN n. 12/50. Istituto Superiore di Sanità, Rome. http://www.iss.it/binary/publ/cont/12_50_web.pdf. Accessed 26 Jan 2015

Marques SC, RezendeJDGOS Alves LADF, Silva BC, Alves E, Abreu LRD, Piccoli RH (2007) Formation of biofilms by Staphylococcus aureus on stainless steel and glass surfaces and its resistance to some selected chemical sanitizers. Braz J Microbiol 38(3):538–543. doi:10.1590/S1517-83822007000300029

Montanari F, Jezsó V, Donati C (2015) Risk regulation in non-animal food imports. The European Union approach. SpringerBriefs in Chemistry of Foods. Springer, Heidelberg (in press)

Muncke J (2014) Hazards of food contact material. In: Motarjemi Y, Moy G, Todd E (eds) Encyclopedia of food safety. Academic Press, San Diego, London, Waltham

Nema V, Agrawal R, Kamboj DV, Goel AK, Singh L (2007) Isolation and characterization of heat resistant enterotoxigenic *Staphylococcus aureus* from a food poisoning outbreak in Indian subcontinent. Int J Food Microbiol 117(1):29–35. doi:10.1016/j.ijfoodmicro.2007.01.015

Nunes ZG, Martins AS, Altoe ALF, Nishikawa MM, Leite MO, Aguiar PF, Fracalanzza SEL (2005) Indoor air microbiological evaluation of offices, hospitals, industries, and shopping centers. Mem I Oswaldo Cruz 100(4):351–357. doi:10.1590/S0074-02762005000400003

Ölmez H, Kretzschmar U (2009) Potential alternative disinfection methods for organic fresh-cut industry for minimizing water consumption and environmental impact. LWT-Food Sci Technol 42:686–693. doi:10.1016/j.lwt.2008.08.001

O'Toole G, Kaplan HB, Kolter R (2000) Biofilm formation as microbial development. Ann Rev Microbiol 54:49. doi:10.1146/annurev.micro.54.1.49

Parish ME, Beuchat LR, Suslow TV, Harris LJ, Garrett EH, Farber JN, Busta FF (2003) Methods to reduce/eliminate pathogens from fresh and fresh-cut produce. Compr Rev Food Sci Food Saf 2(s1):161–173. doi:10.1111/j.1541-4337.2003.tb00033.x

Parisi S (2002) La stesura del Piano di Autocontrollo nel comparto agro-alimentare. Il Chimico Italiano XIII 2(25):28

Parisi S (2009) Intelligent packaging for the food industry. In: Gardiner FL, Carter EJ (eds) Polymer electronics – a flexible technology. Smithers Rapra Technology Ltd, Shawbury

Parisi S (2010) HACCP assessment: studio di nuovi piani di campionamento in forma ridotta nel campo lattiero-caseario. Dissertation, University of Messina

Parisi S (2011) Food packaging and technological compliance. The importance of correct storage procedures. Food Packag Bull 20(9, 10):14–18

Parisi S (2012) Food packaging and food alterations. The user-oriented approach.Retail Consortium Smithers Rapra Technology Ltd, Shawbury

Parisi S (2013) Food industry and packaging materials. User-oriented guide-lines for users. Smithers Rapra Technology Ltd, Shawbury

Parisi S, Delia S, Laganà P (2009a) Possible connections between food packaging and microbiological spreading. World Food Reg Rev 19(5):15–17

Parisi S, Delia S, Laganà P (2009b) Possible connections between food packaging and microbiological spreading. Part 2. World Food Reg Rev 19(6):9–21

Parisi S, Delia S, Laganà P (2009c) Possible connections between food packaging and microbiological spreading. Part 3. World Food Reg Rev 19(7):19–21

Pisanello D (2014) Chemistry of foods: EU legal and regulatory approaches. SpringerBriefs in Chemistry of Foods, Springer, Heidelberg

Shah RK, Sekulic DP (2003) Fundamentals of heat exchanger design. Wiley, Hoboken

Sharma M, Anand SK (2002) Biofilms evaluation as an essential component of HACCP for food/dairy processing industry–a case. Food Control 13(6):469–477. doi:10.1016/S0956-7135(01)00068-8

Singh RP (2011) Food engineering. In: Campbell-Platt G (2011) Food science and technology. Wiley, Chichester

Sousa CL, Freitas JA, Lourenço LFH, Araujo EAF, Peixoto Joele MRS (2014) Microbiological contamination of surfaces in fish industry. Afr J Microbiol Res 8(5):425–431. doi:10.5897/AJMR2013.6319

Stanfield P (2003) Sanitation of food processing equipment. In: Hui YH, Bruinsma LB, Gorham J, Nip WK, Tong PS, Ventresca P (eds) Food plant sanitation. Marcel Dekker, New York, p 191

Stilo A, Parisi S, Delia S, Anastasi F, Bruno G, Laganà P (2009) Food security in Europe: comparison between the “Hygiene Package” and the British Retail Consortium (BRC) and International Food Standard (IFS) protocols. Ann Ig 21(4):387–401

Sutherland IW (2001) Biofilm exopolysaccharides: a strong and sticky framework. Microbiol 147:3–9

Takeuchi K, Frank JF (2000) Penetration of Escherichia coli O157:H7 into lettuce tissues as affected by inoculum size and temperature and the effect of chlorine treatment on cell viability. J Food Prot 63:434–440

Tompkin RB (2002) Control of Listeria monocytogenes in the food-processing environment. J Food Prot 65(4):709–725

Tompkin RB, Scott VN, Bernard DT, Sveum WH, Gombas KS (1999) Guidelines to prevent post-processing contamination from Listeria monocytogenes. Dairy Food Env Sanitation 19:551–603

Ueda S, Kuwabara Y (2007) Susceptibility of biofilm Escherichia coli, Salmonella enteritidis and Staphylococcus aureus to detergents and sanitizers. Biocontr Sci 12(4):149–153

Wierzbicka A, Gudmundsson A, Pagels J, Dahl A, Löndahl J, Bohgard M (2009) Fine and ultrafine particles in a supermarket in Sweden. In: Proceedings of healthy buildings 2009, paper 522. International Society of Indoor Air Quality and Climate. http://lup.lub.lu.se/luur/download?func=downloadFile&recordOId=1481758&fileOId=1481902. Accessed 15 Jan 2015

Yazdankhah SP, Scheie AA, Høiby EA, Lunestad BT, Heir E, Fotland TØ, Naterstad K, Kruse H (2006) Triclosan and antimicrobial resistance in bacteria: an overview. Microb Drug Resist 12 (2):83–90. doi:10.1089/mdr.2006.12.83

Chapter 4
The Hygienic Prevention of Food Contamination: The Role of Technology

Abstract The problem of microbial contamination in foods is strictly correlated with the regulatory norms and hygiene obligations. For this and other important reasons, the attention of researchers is correlated with the study of food-borne diseases (from the medical viewpoint) and the control of food-borne pathogens in the food production and manipulation environment. The introduction of useful microbiological criteria is surely needed. This effort must include the establishment and the practical implementation of reliable sampling plans, the definition of food lots or batches and correlated guidelines for public and private laboratories. On these bases, the management of food-borne pathogens and spoilage microorganisms is possible, on condition that a sufficient number of observations are available and carefully studied. The use of mathematical predictive models and derived software programs may be also useful in the ambit of risk assessment and HACCP studies. This chapter is dedicated to a simplified description of the basic strategies for the eradication of microbial contamination in food production environments: thermal treatments; chemical systems; and non-thermal treatments.

Keywords Cleaning · Critical control point · Disinfection · Good manufacturing practice · HACCP · Pasteurisation · Standard operating procedure · Sterilisation · Thermal treatment

4.1 Microbial Contamination in Food Industries and Correlated Countermeasures: An Overview

The problem of microbial contamination in foods is strictly correlated with the regulatory norms and hygiene obligations worldwide (Montanari et al. 2015; Pisanello 2014; Stilo et al. 2009). For this and other important reasons, including the management of food crises in the food chain, the so-called 'microbial risk' is the best known and investigated topic in food technology. At present, the number of scientific works with some correlation to food safety and microbial outbreaks is

G. Gurnari, *Safety Protocols in the Food Industry and Emerging Concerns*,
Chemistry of Foods, DOI 10.1007/978-3-319-16492-2_4

remarkable. The attention of researchers is correlated with the study of food-borne diseases (from the medical viewpoint) and the control of food-borne pathogens (Forsythe 2013) in the food production and manipulation environment.

From the viewpoint of food technologists and medical researchers, the introduction of useful microbiological criteria is surely needed. This effort must include the establishment and the practical implementation of reliable sampling plans, the definition of food 'lots' or 'batches' and correlated guidelines for public and private laboratories (Forsythe 2013). On these bases, the management of food-borne pathogens and spoilage microorganisms is possible, on condition that a sufficient number of observations are available and carefully studied. In fact, the in vitro behaviour of many life forms may differ from the real behaviour in complex systems such as food matrices (meats, milk, vegetables, processed foods, etc.). The study and the practical prediction of certain bacteria by means of mathematical predictive models and derived software programs—the UK Food MicroModel, the Pathogen Modeling Program, the Sym'previus, the Seafood Spoilage and Safety Predictor, etc.—can give different results in comparison with experimental data (McMeekin et al. 2006; Wilson et al. 2002). These 'fail-safe' discrepancies often concern differences between observed and real growth of a specified microorganism in a food matrix (Wilson et al. 2002).

The management of microbial hazards cannot be fully implemented without solid bases. Reliable hygiene production practices have to be decided and realised, including (Forsythe 2013):

(a) Personal hygiene and training sessions for food operators (the importance of food-transmitted microorganisms by handlers in the food chain has to be highlighted);
(b) Cleaning and sanitising procedures;
(c) Choice of the 'right' detergent in cleaning operations;
(d) Choice of the 'right' disinfectant in sanitising operations;
(e) Assessment and inspection (on a regular basis) of the efficacy of cleaning and sanitising procedures;
(f) Introduction of the high control gate between the external areas (dirty) and inside (clean).

Subsequently, the general Hazard Analysis and Critical Control Points' (HACCP) approach has to be considered (Bas et al. 2006; Forsythe 2013; Santana et al. 2009). This apparently complex strategy requires that adequate 'prerequisite programs' are implemented in food production, packaging and distribution plants (Bas et al. 2006; Yavari et al. 2014):

- Good manufacturing practices (GMP);
- Standard operating procedures (SOP);
- Hygiene production practices;
- Adequate food processing and packaging equipments, from the viewpoint of sanitisation (proper hygienic design);
- Reliable and regular inspection and maintenance of food machinery;

- Adequate procedures and recorded data with regard to supplier selection;
- Reliable procedures for the control of cross-contamination episodes;
- Adequate and up-to-date procedures for storage of raw materials and needed devices.

On these bases, the seven HACCP principles can be considered with the aim of establishing the correct management plan regarding different food safety (chemical, microbiological, physical) risks (Forsythe 2013; Mukundan 2005):

(1) Hazard analysis
(2) Definition of Critical Control Points (CCP)
(3) Definition of critical limits regarding every CCP
(4) CCP monitoring action
(5) Establishment and implementation of corrective actions
(6) Evaluation of results from corrective actions
(7) Reliable record of HACCP data and analyses
(8) Periodic updates that take account of the achievements and innovation in the industry of chemicals for disinfection and sanitisation.

As a result, the microbiological risk—a food hygiene matter—can be evaluated in the HACCP scope. Generally, this hazard is strictly connected with outbreaks of microbial origins and examples of chemical contamination of microbial origin (Andreis and Ottaviani 2002; Bonadonna et al. 2004; Hardy 1999; Mortlock et al. 1999; Oteri and Ekanem 1989). The management of microbial risk is required due to two main reasons:

(a) Produced foods have to be safe for human consumption. As a consequence, the microbial population with negative effects on human health and/or food features has to be eradicated or reduced (Gram et al. 2002; Monk et al. 1995). However, the growth of microbial populations with clear and positive effects on human health and product features should be promoted (Bergamini et al. 2005; Granato et al. 2010; Salminen et al. 1998)
(b) Foods also have to be safe on the legal ground in regard to regulatory protocols and supporting documents on food safety and microbial contamination. With regard to this economic area only, the Commission Regulation (EC) No 2073/2005 and subsequent amendment concern microbiological criteria in foodstuffs (Montanari et al. 2015; Pisanello 2014).

Because of the remarkable number of food rejections and notification procedures in the EU for microbial causes, the problem of food safety has been often considered from the point of view of medical hygienists. On the other hand, the role of technological procedures in food industries should be carefully studied. This chapter is dedicated to the simplified description of basic strategies for the eradication of microbial contamination in food production environments. In detail, the following sections concern:

- Sterilisation and other thermal treatments in food processing (Sect. 4.2);
- Chemical treatments in food industries (Sect. 4.3);
- Non-thermal treatments in food industries (Sect. 4.4).

Cleaning operations and chemical disinfectants are discussed in Chaps. 5–7. These discussions take also into account new decontamination strategies (Giordano et al. 2012; Stilo et al. 2009) such as the use of electrolysed oxidising water for wash sanitation in the industry for minimally processed vegetables.

4.2 Sterilisation and Other Thermal Treatments in Food Processing

Historically, the production of 'safe foods' has been associated with canned products such as sterilised fish products, canned tomato sauces, etc. In fact, similar preserved foods should be able to maintain their own chemical and physical features during extended temporal periods (Parisi 2004, 2012). As a result, the use of thermally drastic processes is necessary when speaking of preserved fish, meat or vegetable products.

In general, the definition of 'commercially sterile' food means a series of concomitant conditions with regard to processed foods. According to the Food and Drug Administration, Code of Federal Regulations, Title 21, commercially sterile foods should be obtained by thermal methods that are able to eradicate (FDA 2014):

(a) 'Microorganisms capable of reproducing in the food under normal and non-refrigerated conditions of storage and distribution'
(b) 'Viable microorganisms, including anaerobic spores, of public health concern'.

In addition, the use of different (mixed) treatments, such as the concomitant application of heat and the control of water activity, is allowed on condition that the final product is 'free of microorganisms capable of reproducing in the food under normal non-refrigerated conditions of storage and distribution' (FDA 2014).

The Canadian Food Inspection Agency defines 'commercially sterile' foods in a similar way (Bratt 2010). Both institutions consider also the problem of equipment and containers used in aseptic processing. Product contact surfaces of equipment and containers have to be free from viable forms of microorganisms capable of growing in canned food under normal non-refrigerated conditions of storage and distribution' (FDA 2014; Von Bockelmann and Von Bockelmann 1986). Interestingly, pathogen agents are considered as 'viable microorganisms having public health significance'; on the other hand, life forms of non-health significance (spoilage microorganisms) are cited (FDA 2014; McGarrahan 1982; Von Bockelmann and Von Bockelmann 1986).

The most known and successful thermal treatments are pasteurisation and sterilisation, although new technologies—actually, new developments of the above-mentioned processes such as ‘high pressure processing’ (Barbosa-Cánovas and Juliano 2008)—have been developed recently. The main difference between the two man choices is correlation with the commercial storage of final products. In fact, pasteurisation provides a good inactivation of pathogen agents (Fu 2006); on the other hand, the pasteurised product needs subsequent storage treatment during its commercial life, until the final date of selling or utilisation (Parisi 2002a). Conditions of pasteurisation treatments (60–65 °C for 30 min, or 88 °C for a few seconds only), and correlated sensorial modifications of heated foods, depend mainly on the pH and the microbial ecology of foods. In certain situations ($pH < 4.5$), the food technologist prefers to consider enzyme inactivation or the thermal destruction of spoilage microorganisms (Ramesh 2007). The current industrial pasteurisation treatments are defined as follows (Maranon et al. 2006; McCormick et al. 2005; Murphy et al. 2003; Patterson 1942; Ramesh 2007; Stabel 2001; Wheeler et al. 1987):

(a) In-package pasteurisation (interesting feature: a sort of gradient temperature may be required in certain situations, depending on chosen packages)
(b) Pasteurisation before packaging (without containers; possibility of preheating)
(c) Batch pasteurisation (62.8 °C, 30 min). This process is designed for fluids
(d) Continuous pasteurisation (71.5 °C, 15 s). This process is specifically designed for fluid foods such as milks for curd processing
(e) Flash pasteurisation. This process is carried out at temperatures that are higher than the usual pasteurisation values (example: 80 °C + additional 5 °C) for a minute only, just before the final packaging. This method, specifically designed for fruit juices, needs adequate de-aerators because fresh juices contain a considerable amount of dissolved oxygen.

In regard to sterilisation, the desired inactivation includes also spores. For this reason, sterilisation has to be carried out under pressure and with thermal values exceeding 100 °C: typical values should be between 121 and 129 °C (Fu 2006). Interestingly, sterilisation treatments are extensively used with the aim of producing three main categories of food products (Fu 2006):

- Canned foods (this is the traditional type of sterilised foods);
- Packaged foods in aseptic conditions (ultra-time-temperature processes are carried out in a very short time);
- Irradiated foods (this category of food products should be considered as an experimental innovation, at present).

By contrast, pasteurisation appears to have limited applications at present: the main uses are correlated to the production of liquid and fluid products such as milks and fruit juices (Fu 2006). Some practical innovation has recently introduced microwave pasteurisation: the heating of packaged food products at high temperatures is an interesting option, particularly in Europe. The main advantages are the extension of shelf life dates without the addition of preservatives and the reduction of heating times (Burfoot et al. 1988, 1996; Cañumir et al. 2002; Fu 2006). The same possibility is workable with regard to sterilisation processes: it has been reported that microwave sterilisation may allow the treatment of pre-packed foods without distinction between liquid, solid and semi-solid products (Fu 2006; Israelsson et al. 2005; Mullin 1995; Sukaribin and Khalid 2009). In addition, sensorial features of foods should be sensibly preserved with microwave sterilisation in comparison with other processes such as ohmic heating (Fu 2006). On the other hand, several practical difficulties, such as the lack of heating uniformity, and consequent hygienic concerns have to be highlighted. At present, microwave sterilisation is considered with some suspect, although this technology and the analogous pasteurisation system continue to receive attention (Fu 2006).

Classical sterilisation treatments are subdivided into two categories (Barbosa-Cánovas and Juliano 2008; Ramesh 2007):

(a) Heating processes: This category concerns 'bulk canning' (also named 'in-container sterilisation') methods and aseptic sterilisation processes.
(b) Non-thermal processes: high pressure processing (HPP), pulsed electric fields, ultraviolet (UV) radiation, food irradiation, chemical treatments, use of magnetic fields, etc.

It must be clarified that non-thermal treatments are not classified as classical sterilisation treatments. However, because of positive effects in terms of inactivation, these strategies have been considered as alternative methods. Non-thermal processes are discussed briefly in Sect. 4.4, while chemical treatments are discussed in Sect. 4.3 without the inclusion of normal preservation systems (use of vegetable oils, smoking processes, etc.) in food industries.

For some years, chemical industries are trying to apply nanotechnology, already widely used in other productions (cosmetics, protective films, pharmaceutical, aviation, aerospace, polymers, etc.), to products for the hygienic prevention on surface and machinery. While in vitro tests are providing excellent results, studies and research in the field are still too few to have sufficient scientific evidence (Cubadda et al. 2013).

4.3 Chemical Treatments in Food Industries

Food industries can use thermal treatments for inactivating undesired microorganisms with well-known results. However, non-thermal processes may be also useful. In addition, food technologists may choose other strategies, such as the use of chemical agents or techniques, provided that safety, integrity and legality of food products are not damaged.

The most known and used chemical compounds for limitation of microbial spoilage and the eradication of pathogen agents in food industries are given in the following list, with the exclusion of preservatives and food additives (NACMCF 2006; Parish et al. 2003; Park et al. 2001; Wang et al. 2004; Weissinger et al. 2000):

- Acidified sodium chlorite
- Anhydrous ammonia
- Chlorine dioxide
- Ethylene oxide
- Hypochlorites
- Peroxyacids
- Organic acids
- Ozone.

Similar substances are often used as an accessory strategy when thermal or non-thermal treatments (freezing, refrigeration, acidification, modified atmosphere packaging, etc.) are considered (NACMCF 2006). This reflection should be always taken into account because many chemicals may reduce pathogens and spoilage bacteria, but their total eradication is impossible. The inactivation effect of chemicals depends on many factors which have to be carefully managed (NACMCF 2006). For example, the concentration of the specified chemical substance has to be decided with other parameters such as the antimicrobial spectrum and the immediate lethal effect, the chemical composition of the final food, etc. (NACMCF 2006; Parisi 2002b).

4.4 Non-thermal Treatments in Food Industries

Non-thermal processes can be very effective for microbial inactivation in food industries. The most used and studied systems are included in the following non-exhaustive list (NACMCF 2006):

(1) Pulsed electric fields (PEF)
(2) HPP systems
(3) UV radiation
(4) Food irradiation.

On the other hand, systems such as oscillating magnetic fields, infrared processing, non-thermal plasma systems, are defined as ‘interesting’ technologies without sufficient information at present compared with traditional heating treatments (pasteurisation).

The application of PEF treatments to foods should be considered with care. These systems are carried out with the simple placement of foods between two electrodes (NACMCF 2006). The aim of the process is to inactivate microbial populations by means of high-voltage electric fields (between 20 and 80 kV/cm). At present, the explanation of microbial inactivation seems correlated to the lack of electromechanical resistance of cell membranes. In addition, the higher the field strength, the lower the general resistance of microorganisms (NACMCF 2006; Russell 2002). Another important advantage of PEF techniques is the effective minimisation of organoleptic and physical features (NACMCF 2006).

On the other hand, it has been reported that PEF processes are currently applied in regard to fluids because the distance between charged electrodes should not exceed 3 mm. For this design requirement, it appears that solid food may not be treated adequately with PEF systems (NACMCF 2006), although semi-solid food applications have been reported with success (Zhang et al. 1994). Moreover, the efficacy of microbial inactivation should be validated (NACMCF 2006). With regard to most resistant life forms, more research is needed because the available results are not exhaustive: at present, it may be assumed that microorganisms without lipid membranes such as rotavirus are PEF-resistant (Khadre and Yousef 2002). Probably, studies of PEF inactivation are complicated because of the remarkable number of involved factors: processing parameters such as electric field strength, number of pulses and temperature, etc.; food-related features such as electrical conductivity, pH, etc.; possible synergistic effects when organic acids or antimicrobials are added; and other possible options (Liang et al. 2002; Manas and Pagán 2005; NACMCF 2006; Rodrigo et al. 2003a, b; Smelt et al. 2002).

HPP systems are generally applied to packaged ‘ready-to-eat’ meat and poultry products against *L. monocytogenes* (NACMCF 2006). In addition, these strategies have been also used for seafood products and some types of processed fruits and vegetables. However, the practical application of HPP is currently limited because of possible damages to several products, although minimal damage has been reported with reference to flavours, aromas and other sensible molecules (NACMCF 2006). In addition, HPP appears to be insufficient against sporeforming agents if other synergic treatments are not applied (Barbosa-Cánovas and Juliano 2008; Heinz and Knorr 2001; NACMCF 2006).

From the technical viewpoint, HPP involves hydrostatic compression with pressures between 100 and 1000 MPa (NACMCF 2006). As a result, microorganisms suffer damages, although it has been reported that spores are more resistant than vegetative cells (Sale et al. 1970). In addition, there is a remarkable difference between Gram-positive and Gram-negative bacteria: the second group appears less resistant to HPP techniques. These differences confirm that HPP inactivation may depend on a notable number of concomitant factors which should be considered, such as temperature, pH, isotonic strength, amount of organic acids, etc. (Heinz and Knorr 2001; NACMCF 2006).

UV radiation has been reported to be effective against viruses and bacteria in some food products, particularly with regard to fluids such as water and apple juice (NACMCF 2006; Quintero-Ramos et al. 2004; Sastry et al. 2000). In fact, UV radiations between 200 and 280 nm (ideally 2534 Å or 253 nm) may inactivate viruses and bacteria by means of the destruction of deoxyribonucleic acid molecular bonds, but the practical result—in terms of log units—has to be validated for specific application (NACMCF 2006; Sastry et al. 2000). Good microbial inactivation can be obtained in water if all ideal sections of the treated liquid receive at least 400 J/m^2 (NACMCF 2006; Sommer et al. 2000). Another important feature of UV radiation techniques is the new development of pulsed UV radiation systems. ‘Pulsed light’ systems concern two different techniques involving the treatment of food (or packaging) surfaces with 1–3 ms pulsed radiations. The difference is

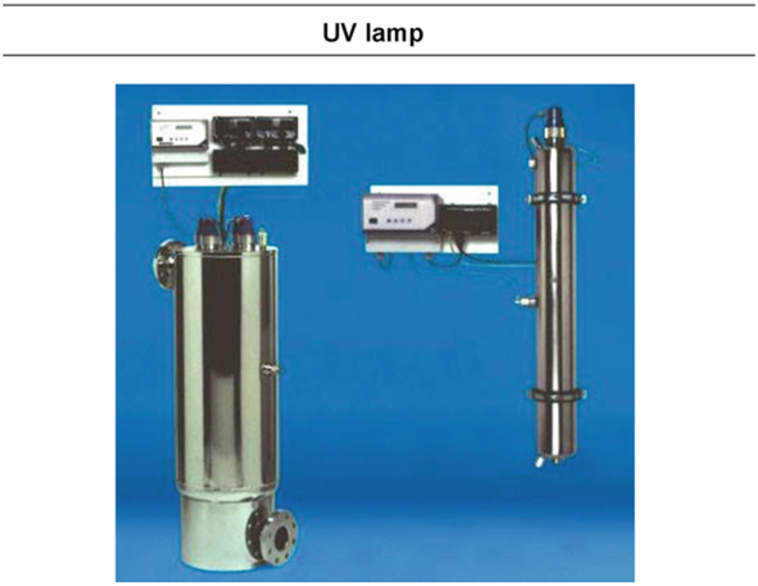


Fig. 4.1 UV radiation techniques have been recently modified. At present, the newest development concerns the use of pulsed UV radiation systems. 'Pulsed light' systems concern two different techniques involving the treatment of food (or packaging) surfaces with 1–3 ms pulsed radiations by means of UV lamps. The difference is the use of wavelengths in the UV region (up to 248 nm) or the application of radiations in the 200–1000 nm range

(Fig. 4.1) the use of wavelengths in the UV region (up to 248 nm) or the application of radiations in the 200–1000 nm range (Barbosa-Canovas et al. 2000; Butz and Tauscher 2002; Elmnasser et al. 2007).

On the other hand, the real effectiveness of UV light needs to be evaluated carefully, depending on many factors (NACMCF 2006) without direct connection to technical system requirements (Bolton and Linden 2003). For example, it has been reported that sporeforming life forms can survive after this treatment for several foods, with the exclusion of water and fruit juices. In addition, damaged microorganisms may be capable of recovery in particular conditions (NACMCF 2006). Substantially, UV light damages nucleic acids; this phenomenon should assure reliable inactivation of viruses and bacteria. However, it has been reported that some microorganisms such as *E. coli* may enzymatically repair themselves (Sommer et al. 2000). The composition and physical features of foods are critical factors: homogeneous fluids, transparency, and superficial shape [if solid foods are considered, dimensional features of fluid columns, colorimetry, etc. (NACMCF 2006)].

The main problem in irradiation techniques is generally correlated with consumers' worries (Cardello et al. 2007; Miles et al. 2004; Rollin et al. 2011; Rosati and Saba 2004). Technically, foods are exposed to ionising radiation with the aim of inactivating pathogen agents and delaying deterioration in certain foods (Rollin et al. 2011). Ionising radiations are electron beams, X-rays or gamma-rays.

Because of inactivation effects from the microbiological viewpoint, food irradiation is also called ‘cold pasteurisation’ (Rollin et al. 2011). On the other hand, it has to be highlighted that low and average doses of radiation cannot eradicate all life forms from foods; for this reason, the term ‘cold pasteurisation’ is particularly appropriate (Rollin et al. 2011). In general, the upper dose does not exceed 10 kGray (kGy), in accordance with the Joint Expert Committee on Food Irradiation, the International Atomic Energy Agency and the World Health Organization. These organisations have concluded that food irradiation does not pose toxicological hazards or other risks when this dose is respected (NACMCF 2006; Rollin et al. 2011; World Health Organization 1981).

With regard to main food applications, it should be also remembered that food irradiation is not recommended in some situations. For example, dairy foods are not irradiated because of possible sensorial modifications. The same concern may occur (Buck et al. 2003; Lu et al. 1988; NACMCF 2006) when certain vegetables are irradiated with doses higher than 10 kGy (aim: prevention of sprouting or disinfestation).

Food irradiation should be always validated in comparison with traditional pasteurisation treatments. The following factors should be considered:

(a) Type of food product (chemical composition, packaging materials, density of food, quantity of water, etc.);
(b) Type of ionising radiation and appropriate absorbed dose;
(c) Targeted microorganism.

For these reasons, the use of food irradiation can be recommended or unallowed depending on obtainable results and the regulatory framework.

References

Andreis G, Ottaviani F (eds) (2002) Manuale delle Sicurezza Microbiologica degli Alimenti e delle Acque. Oxoid SpA, Garbagnate M.se

Barbosa-Cánovas GV, Juliano P (2008) Food sterilization by combining high pressure and thermal energy. Food engineering: integrated approaches. Springer, New York, pp 9–46. doi:10.1007/978-0-387-75430-7

Barbosa-Canovas GV, Schaffner DW, Pierson MD, Zhang QH (2000) Pulsed light technology. J Food Sci Suppl 65(4):82–85. doi:10.1111/j.1750-3841.2000.tb00621.x

Bas M, Ersun AS, Kivanç G (2006) Implementation of HACCP and prerequisite programs in food businesses in Turkey. Food Control 17:118–126. doi:10.1016/j.foodcont.2004.09.010

Bergamini CV, Hynes ER, Quiberoni A, Suárez VB, Zalazar CA (2005) Probiotic bacteria as adjunct starters: influence of the addition methodology on their survival in a semi-hard Argentinean cheese. Food Res Int 38(5):597–604. doi:10.1016/j.foodres.2004.11.013

Bolton JR, Linden KG (2003) Standardization of methods for fluence (UV dose) determination in bench-scale UV experiments. J Env Eng 129(3):209–215. doi:10.1061/(ASCE)0733-9372(2003)129:3(209)

Bonadonna L, Briancesco R, Donia D, Ottaviani M, Veschetti E, Divizia M (2004) Aspetti igienico-sanitari delle acque del fiume Tevere: presenza di protozoi patogeni e rapporti di correlazione con parametri microbiologici e chimico-fisici. Ann Ig 16(1–2):273–280

Bratt L (ed) (2010) Fish canning handbook. Wiley-Blackwell, Oxford. doi:10.1002/9781444323405

Buck JW, Walcott RR, Beuchat LR (2003) Recent trends in microbiological safety of fruits and vegetables. Plant Health Prog. http://www.plantmanagementnetwork.org/pub/php/review/2003/safety/. Accessed 16 Jan 2015

Burfoot D, Griffin WJ, James SJ (1988) Microwave pasteurisation of prepared meals. J Food Eng 8(3):145–156. doi:10.1016/0260-8774(88)90050-7

Burfoot D, Railton CJ, Foster AM, Reavell SR (1996) Modelling the pasteurisation of prepared meals with microwaves at 896 MHz. J Food Eng 30(1):117–133

Butz P, Tauscher B (2002) Emerging technologies: chemical aspects. Food Res Int 35(2):279–284. doi:10.1016/S0963-9969(01)00197-1

Cañumir JA, Celis JE, de Bruijn J, Vidal LV (2002) Pasteurisation of apple juice by using microwaves. LWT-Food Sci Technol 35(5):389–392. doi:10.1006/fstl.2001.0865

Cardello AV, Schutz HG, Lesher LL (2007) Consumer perceptions of foods processed by innovative and emerging technologies: a conjoint analytic study. Innov Food Sci Emerg Technol 8(1):73–83. doi:10.1016/j.ifset.2006.07.002

Cubadda F, Aureli F, D'Amato M, Raggi A, Mantovani A (2013) Proceedings of the conference 'nanomaterials in the food sector: new approaches for safety assessment', Rome, 27 Sept 2013. Rapporti ISTISAN N. 13/48, Istituto Superiore di Sanità, Rome. http://www.iss.it/binary/publ/cont/13_48_web.pdf. Accessed 26 Jan 2015

Elmnasser N, Guillou S, Leroi F, Orange N, Bakhrouf A, Federighi M (2007) Pulsed-light system as a novel food decontamination technology: a review. Can J Microbiol 53(7):13–821. doi:10.1139/W07-042

FDA (2014) Code of federal regulations, title 21, vol 2, Part 113, revised 1st April 2014. US Food and Drug Administration, Silver Spring. http://www.accessdata.fda.gov/scripts/cdrh/cfdocs/cfcfr/cfrsearch.cfm?fr=113.3. Accessed 18 Dec 2014

Forsythe SJ (2013) The microbiology of safe food. Wiley, Chichester

Fu YC (2006) Microwave heating in food processing. In: Hui YH (ed) Handbook of food science, technology, and engineering, vol 3. CRC Press, Boca Raton

Giordano R, Sorbo A, Patriarca V, Ciaralli L (2012) Report of the 14th proficiency testing on meat, milk and fish of the EU Reference laboratory for chemical elements in food of animal origin. Rapporti ISTISAN n. 12/56, Istituto Superiore di Sanità, Rome. http://www.iss.it/binary/publ/cont/12_56_web.pdf. Accessed 26 Jan 2015

Gram L, Ravn L, Rasch M, Bruhn JB, Christensen AB, Givskov M (2002) Food spoilage-interactions between food spoilage bacteria. Int J Food Microbiol 78(1):79–97. doi:10.1016/S0168-1605(02)00233-7

Granato D, Branco GF, Nazzaro F, Cruz AG, Faria JA (2010) Functional foods and nondairy probiotic food development: trends, concepts, and products. Compr Rev Food Sci Food Saf 9(3):292–302. doi:10.1111/j.1541-4337.2010.00110.x

Hardy A (1999) Food, hygiene, and the laboratory. A short history of food poisoning in Britain, circa 1850–1950. Soc Hist Med 12(2):293–311. doi:10.1093/shm/12.2.293

Heinz V, Knorr D (2001) Effect of high pressure on spores. In: Hendrickx MEG, Knorr D, Ludikhuyze L, Van Loey A, Heinz V (eds) Ultra high pressure treatments of foods. Springer Business + Media, New York, pp 77–116. doi:10.1007/978-1-4615-0723-9_4

Khadre MA, Yousef AE (2002) Susceptibility of human rotavirus to ozone, high pressure and pulsed electric field. J Food Prot 65(9):1441–1446

Israelsson A, Pettersson A, Utas J (2005) Storage package and a method for packaging. US Patent 6,848,574, 01 Feb 2005

Liang Z, Mittal GS, Griffiths MW (2002) Inactivation of Salmonella typhimurium in orange juice containing antimicrobial agents by pulsed electric field. J Food Prot 65(7):1081–1087

Lu JY, Stevens C, Yakubu P, Loretan PA, Eakin D (1988) Gamma, electron beam and ultraviolet radiation on control of storage rots and quality of Walla Walla onions. J Food Process Preserv 12(1):53–62. doi:10.1111/j.1745-4549.1988.tb00066.x

Manas P, Pagán R (2005) Microbial inactivation by new technologies of food preservation. J Appl Microbiol 98(6):1387–1399. doi:10.1111/j.1365-2672.2005.02561.x

Maranon E, Castrillon L, Fernández JJ, Fernández Y, Peláez AI, Sánchez J (2006) Anaerobic mesophilic treatment of cattle manure in an upflow anaerobic sludge blanket reactor with prior pasteurization. J Air Waste Manag Assoc 56(2):137–143. doi:10.1080/10473289.2006.10464448

McCormick KE, Han IY, Acton JC, Sheldon BW, Dawson PL (2005) In-package pasteurization combined with biocide-impregnated films to inhibit Listeria monocytogenes and Salmonella typhimurium in Turkey bologna. J Food Sci 70(1):M52–M57. doi:10.1111/j.1365-2621.2005.tb09046.x

McGarrahan ET (1982) Considerations necessary to provide for sterilized milk and milk products in hermetically sealed, nonrefrigerated containers. J Dairy Sci 65(10):2023–2034. doi:10.3168/jds.S0022-0302(82)82455-7

McMeekin TA, Baranyi J, Bowman J, Dalgaard P, Kirk M, Ross T, Schmid S, Zwietering MH (2006) Information systems in food safety management. Int J Food Microbiol 112(3):181–194. doi:10.1016/j.ijfoodmicro.2006.04.048

Miles S, Brennan M, Kuznesof S, Ness M, Ritson C, Frewer LJ (2004) Public worry about specific food safety issues. Brit Food J 106(1):9–22. doi:10.1108/00070700410515172

Monk JD, Beuchat LR, Doyle MP (1995) Irradiation inactivation of food-borne microorganisms. J Food Prot 58(2):197–208

Montanari F, Jezsó V, Donati C (2015) Risk regulation in non-animal food imports. The European Union approach. SpringerBriefs in Chemistry of Foods. Springer, Heidelberg (in press)

Mortlock MP, Peters AC, Griffith CJ (1999) Food hygiene and hazard analysis critical control point in the United Kingdom food industry: practices, perceptions, and attitudes. J Food Prot 62(7):786–792

Mullin J (1995) Microwave processing. In: Gould GW (ed) New methods of food preservation. Springer Science + Business Media, Dordrecht, pp 112–134. doi:10.1007/978-1-4615-2105-1_6

Murphy RY, Duncan LK, Driscoll KH, Marcy JA (2003) Lethality of Salmonella and Listeria innocua in fully cooked chicken breast meat products during postcook in-package pasteurization. J Food Prot 66(2):242–248

Mukundan MK (2005) Quality and safety in indian seafood industry. Central Institute of Fisheries Technology (CIFT), CIFT Winter School. http://210.212.228.207/bitstream/handle/123456789/1244/Quality%20and%20safety%20in%20Indian%20seafood%20industry.pdf?sequence=1. Accessed 12 Jan 2015

NACMCF (2006) Requisite scientific parameters for establishing the equivalence of alternative methods of pasteurization. J Food Prot 69(5):1190–1216

Oteri T, Ekanem EE (1989) Food hygiene behaviour among hospital food handlers. Pub Health 103(3):153–159. doi:10.1016/S0033-3506(89)80069-1

Parish ME, Beuchat LR, Suslow TV, Harris LJ, Garrett EH, Farber JN, Busta FF (2003) Methods to reduce/eliminate pathogens from fresh and fresh-cut produce. Compr Rev Food Sci Food Saf 2(s1):161–173. doi:10.1111/j.1541-4337.2003.tb00033.x

Parisi S (2002a) I fondamenti del calcolo della data di scadenza degli alimenti: principi ed applicazioni. Ind Aliment 417:905–919

Parisi S (2002b) La stesura del Piano di Autocontrollo nel comparto agro-alimentare. Il Chimico Italiano XIII 2(25):28

Parisi S (2004) Alterazioni in imballaggi metallici termicamente processati. Gulotta Press, Palermo

Parisi S (2012) Food packaging and food alterations. The user-oriented approach. Smithers Rapra Technology Ltd, Shawbury

Park CM, Hung YC, Doyle MP, Ezeike GOI, Kim C (2001) Pathogen reduction and quality of lettuce treated with electrolyzed oxidizing and acidified chlorinated water. J Food Sci 66(9):1368–1372. doi:10.1111/j.1365-2621.2001.tb15216.x

Patterson VC (1942) Continuous pasteurization. US Patent 2,302,469, 17 Nov 1942

Pisanello D (2014) Chemistry of foods: EU legal and regulatory approaches. SpringerBriefs in Chemistry of Foods. Springer, Heidelberg

Quintero-Ramos A, Churey JJ, Hartman P, Barnard J, Worobo RW (2004) Modeling of Escherichia coli inactivation by UV irradiation at different pH values in apple cider. J Food Prot 67:1153–1156

Ramesh MN (2007) Pasteurization and food preservation. In: Rahman MS (ed) Handbook of food preservation, 2nd edn. CRC Press, Boca Raton

Rodrigo D, Barbosa-Canovas GV, Martinez A, Rodrigo M (2003a) Weibull distribution function based on an empirical mathematical model inactivation of Escherichia coli by pulsed electric fields. J Food Prot 66:1007–1012

Rodrigo D, Ruiz P, Barbosa-Canovas GV, Martinez A, Rodrigo M (2003b) Kinetic model for the inactivation of Lactobacillus plantarum by pulsed electric fields. Int J Food Microbiol 81:223–229

Rollin F, Kennedy J, Wills J (2011) Consumers and new food technologies. Trends Food Sci Technol 22(2):99–111. doi:10.1016/j.tifs.2010.09.001

Rosati S, Saba A (2004) The perception of risks associated with food-related hazards and the perceived reliability of sources of information. Int J Food Sci Technol 39(5):491–500. doi:10.1111/j.1365-2621.2004.00808.x

Russell NJ (2002) Bacterial membranes: the effect of chill storage and food processing: a review. Int J Food Microbiol 79(1–2):27–34. doi:10.1016/S0168-1605(02)00176-9

Sale AJH, Gould GW, Hamilton WA (1970) Inactivation of bacterial spores by high hydrostatic pressure. J Gen Microbiol 60(3):323–334. doi:10.1099/00221287-60-3-323

Salminen S, Bouley C, Boutron MC, Cummings JH, Franck A, Gibson GR, Isolauria E, Moreau MC, Roberfroid M, Rowland I (1998) Functional food science and gastrointestinal physiology and function. Br J Nutr 80(S1):S147–S171. doi:10.1079/BJN19980108

Santana NG, Almeida RC, Ferreira JS, Almeida PF (2009) Microbiological quality and safety of meals served to children and adoption of good manufacturing practices in public school catering in Brazil. Food Control 20(3):255–261. doi:10.1016/j.foodcont.2008.05.004

Sastry SK, Datta AK, Worobo RW (2000) Ultraviolet light. J Food Sci 65(S8):90–92

Smelt JPPM, Hellemons JC, Wouters PC, van Gerwen SJC (2002) Physiological and mathematical aspects in setting criteria for decontamination of foods by physical means. Int J Food Microbiol 78(1–2):57–77. doi:10.1016/S0168-1605(02)00242-8

Sommer R, Lhotsky M, Haider T, Cabaj A (2000) UV inactivation, liquid-holding recovery, and photoreactivation of Escherichia coli O157 and other pathogenic Escherichia coli strains in water. J Food Prot 63:1015–1020

Stabel JR (2001) On-farm batch pasteurization destroys mycobacterium paratuberculosis in waste milk. J Dairy Sci 84(2):524–527. doi:10.3168/jds.S0022-0302(01)74503-1

Stilo A, Parisi S, Delia S, Anastasi F, Bruno G, Laganà P (2009) Food security in Europe: comparison between the “Hygiene Package” and the British Retail Consortium (BRC) and International Food Standard (IFS) protocols. Ann Ig 21(4):387–401

Sukaribin N, Khalid K (2009) Effectiveness of sterilisation of oil palm bunch using microwave technology. Ind Crops Prod 30(2):179–183. doi:10.1016/j.indcrop.2009.05.001

Yavari H, Khaniki GJ, Mohseni M, Kamali K (2014) Implementation of hazard analysis critical control point in one of the Iranian flight catering establishment: technical barriers and strategies. J Food Saf Hyg 1(1):1–7

Von Bockelmann BA, Von Bockelmann IL (1986) Aseptic packaging of liquid food products: a literature review. J Agric Food Chem 34(3):384–392. doi:10.1021/jf00069a001

Wang H, Feng H, Luo Y (2004) Microbial reduction and storage quality of fresh-cut cilantro washed with acidic electrolyzed water and aqueous ozone. Food Res Int 37(10):949–956. http://dx.doi.org/10.1016/j.foodres.2004.06.004

Weissinger WR, Chantarapanont W, Beuchat LR (2000) Survival and growth of Salmonella baildon in shredded lettuce and diced tomatoes, and effectiveness of chlorinated water as a sanitizer. Int J Food Microbiol 62(1):123–131. doi:10.1016/S0168-1605(00)00415-3

Wheeler JL, Harrison MA, Koehler PE (1987) Presence and stability of patulin in pasteurized apple cider. J Food Sci 52(2):479–480. doi:10.1111/j.1365-2621.1987.tb06643.x

Wilson PDG, Brocklehurst TF, Arino S, Thuault D, Jakobsen M, Lange M, Farkas J, Wimpenny JWT, Van Impe JF (2002) Modelling microbial growth in structured foods: towards a unified approach. Int J Food Microbiol 73(2):275–289. doi:10.1016/S0168-1605(01)00660-2

World Health Organization (1981) Wholesomeness of irradiated food. Technical report series 654. World Health Organization, Geneva

Zhang Q, Chang FJ, Barbosa-Cánovas GV, Swanson BG (1994) Inactivation of microorganisms in a semisolid model food using high voltage pulsed electric fields. LWT-Food Sci Technol 27 (6):538–543. doi:10.1006/fstl.1994.1106

Part II
Disinfection Techniques and Risks

Chapter 5
Technology, Chemistry and Food Hygiene: A Multidisciplinary Approach for the Reduction of Microbial Risk

Abstract The most recommended approach to the problem of contamination episodes in food industries is the 'Hazard Analysis and Critical Control Points' approach. Food contamination can be caused by different factors. For this reason, the HACCP risk is not defined by a simplified and sectorial viewpoint. Each possible cause (chemical, microbiological, physical) of contamination has to be studied in the food chain without interference by other factors, where possible. As a result, three different risks—microbiological, chemical and physical hazards—can be predicted by food business operators and players of the food chain. Because of the prevailing role and interest in microbial contamination in food products, the microbial risk in foods appears to be the best known investigated topic in food technology. On the other hand, the eradication or the limitation of certain micro-organisms or viruses has to be faced in a multifaceted way. The point of view of physical chemists, engineers and regulatory experts has to be considered with regard to food safety and microbial ecology in edible products for human consumption.

Keywords Chemical risk · Critical control point · Food business operator · HACCP · Microbiological risk · Physical risk · Water activity

5.1 The Microbial Risk in Food Industries: The HACCP System is a Multidisciplinary Approach

The problem of food contamination has been thoroughly investigated in the past decades because of the remarkable number of notified episodes and correlated food-borne diseases (Parish et al. 2003). Because of the multiplicity of possible food-correlated risks, most food business operators (FBO) worldwide have decided to take into account adequate and preventive systems. This 'evolution' has been needed because of many and concomitant factors such as the growth of the human population in urban areas, the diversification of food consumers and the

G. Gurnari, *Safety Protocols in the Food Industry and Emerging Concerns*,
Chemistry of Foods, DOI 10.1007/978-3-319-16492-2_5

introduction of ‘minimally processed foods’. The current market of fresh and ‘long distance’ products determines a new strategy for the preparation and storage of food, beginning with the cold chain. For these reasons, the possibility of food contamination episodes may arise when adequate and specific ‘food management practices’ are not in place.

At present, the most recommended approach to the problem of contamination episodes in food industries is the ‘Hazard Analysis and Critical Control Points’ (HACCP) approach. Other ‘quality assurance programmes’ can be very useful (Barendsz 1998; Stilo et al. 2009). In addition, the management of food contamination episodes has progressively concerned ‘accessory’ materials such as food-contact materials and objects (Parisi 2004a, b).

Food contamination can be caused by different factors. For this reason, the ‘HACCP risk’ is not defined by a simplified and sectorial viewpoint. Each possible cause (chemical, microbiological, physical) of contamination has to be studied in the food chain without interference by other factors, where possible. As a result, three different risks can be predicted by FBO and other players of the food chain:

- The microbiological risk (detection and spreading of pathogen agents and degrading life forms);
- The chemical risk (detection of undesirable and/or dangerous chemicals in food products by different sources);
- The physical risk (detection of harmful foreign bodies in foods: wood fragments, glass, non-edible powders, insects, etc.).

Because of the prevailing role and the interest of microbial contamination in food products in the scientific literature and in regulatory dispositions, the so-called ‘microbial risk’ in foods appears to be the best known investigated topic in food technology (Doyle et al. 2013; Montanari et al. 2015; Pisanello 2014). However, it must be clarified that the management of such a risk in the ambit of HACCP strategies (Sect. 1.3) is not necessarily correlated to microbiology.

Generally, the HACCP plan is on the basis of seven main principles:

(1) Hazard analysis;
(2) Definition of Critical Control Points (CCP);
(3) Definition of critical limits concerning every CCP;
(4) CCP monitoring action;
(5) Establishment and implementation of corrective actions;
(6) Evaluation of results from corrective actions;
(7) Reliable record of HACCP data and analyses.

As a result, the implementation of efficient HACCP plans should include good practice rules with relation to the technological production of foods, the choice and the correct storage of raw ingredients and packaging materials, the construction of food processing machines, cleaning and sanitising procedures, etc. (Panfiloiu et al. 2011). This responsibility cannot be taken by a single person: a small or large group of different experts and involved functions is necessary.

The creation of a so-called ‘HACCP team’ should ideally include (Azanza and Zamora-Luna 2005; Mortimore and Wallace 2013; Panfiloiu et al. 2011):

(a) One member of the executive management;
(b) The so-called HACCP responsible with general leadership;
(c) The responsibility of production operations;
(d) The responsibility for maintenance operations;
(e) The manager of warehouses, including logistic operations in and outside food industries;
(f) The responsibility for raw material supplies, including the purchase of ‘accessory’ or non-edible materials such as packaging. Ideally, this role can be associated with the so-called ‘commercial director’ of food companies;
(g) The responsibility for every production and packaging line;
(h) Other internal or external specialists with adequate knowledge of microbiology, hygiene, risk management, food processing technology, regulatory and disinfection/engineering techniques and chemical engineering.

With regard to the management of microbiological risks, the HACCP plan should be written and regularly validated by the whole team because of the possibility of:

(a) New and emerging hazards, on the one hand and
(b) New strategic opportunities (technologies, interesting additives, improved food machinery designs, innovative software products, new diagnostic systems, etc.) on the other hand.

As a consequence, the structure of a well-designed and implemented HACCP plan should have strong and reliable bases with reference to: microbiology, organic and physical chemistry, engineering and food technology, regulatory, information technology, economics and logistics (Armstrong 2009; Artés et al. 2007; Deasy 2002; McMeekin et al. 2006; Pagán-Rodríguez et al. 2007; Parisi 2002a; Roberto et al. 2006).

This reflection has to be taken into account when dealing with ‘pure’ microbiological risks. In fact, the simple definition of microbial hazard in food products is immediately connected with food-borne diseases and outbreaks. In addition, many food complaints are substantially related to shelf life problems, but the alteration of food products before expected dates is the other face of the microbiological stability during time (Eskin and Robinson 2000; Kilcast and Subramaniam 2000; Labuza and Fu 1993; Parisi 2002a, b).

The problem of microbiological risks has biological causes, but the eradication and/or the limitation of certain microorganisms or viruses have to be faced in a multifaceted way. Consequently, the point of view of physical chemists or engineers is certainly useful in food safety and good manufacturing practices in different plants and environments (Parker and Ring 2001; Singh and Heldman 1993). At the same time, other competencies are needed (Fig. 5.1).

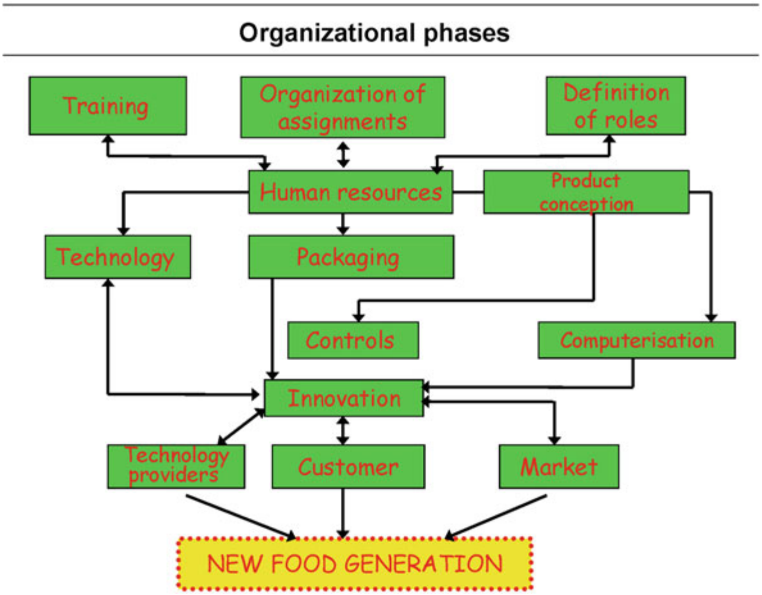


Fig. 5.1 Organisational phases and strategies in the modern food industry

For these reasons, the HACCP approach could be discussed from different viewpoints. This and the following chapters are dedicated to the analytical study of HACCP strategies from non-biological perspectives.

5.2 The Microbial Risk in Food Industries: The Contribution of Organic and Physical Chemistry

Generally, the role of organic chemistry should not be disconnected from the more general ambit of the chemistry of natural substances and processes. In other words, the simple mention of organic toxins concerns contemporarily the world of microbiology and the sector of organic chemistry (biochemistry) at the same time.

On the other hand, the eradication of microbial risks can be obtained by means of chemical strategies. Briefly, the function of organic chemistry in the field of food safety can be evident in the following situations:

(a) Production, development and food-safe use of additives and other chemicals in food formulations, with explicit antimicrobial function (Branen et al. 2001);
(b) Food safety-oriented design, production and development of non-edible materials with preserving functions. Examples: microcrystalline waxes for superficial protection, active packaging systems, new protective polymer films, etc. (Ozdemir and Floros 2004; Parisi 2009);

(c) Food-safety-oriented design, synthesis, production and possible development of chemicals and chemical mixtures with different functions, including the simple superficial preservation. Examples: antimicrobial and edible coating materials with chitosan, etc. (Coma et al. 2002; de Moura et al. 2009);
(d) Food-safety-oriented design, production and safe use of cleaning/sanitising agents and equipments for the food industry and correlated players in the food chain (Kessler 1981; Schmidt 1997);
(e) Technology-oriented design, production and reliable use of diagnostic systems and kits with regard to the evaluation of cleaning and sanitising procedures such as the simple Biuret test (Hola et al. 1990; Hola 1992; Johnson 2005; Lappalainen et al. 2000; Rigarlsford 2006).

The use of food additives, preservation agents and superficial coatings should be carefully evaluated with possible risks. For example, the use of microcrystalline waxes—coating agents for certain cheeses and other products—is not apparently linked with HACCP dangers and microbiological risks (Castle et al. 1993). However, these mineral oil mixtures have to be evaluated by FBO because protected (superficially coated cheeses) are generally destined to lose water (normal ageing process) into the paraffin wax coating during the commercial life of the product. As a result, the chemical composition of cheeses is continually modified on surfaces at the food/paraffin interface. In these conditions, it should be considered that the emission of hydrolysis water and different organic molecules (fatty acids, amino acids, peptones, etc.) can give rise to the following problems (Parisi 2003a, b):

(a) Continuous moisturising of superficial cheese layers with increasing pH and redox potential values;
(b) Possible microbial spoilage because of favourable pH and redox potential values for certain bacteria such as *Escherichia coli*;
(c) Penetration of the aqueous/organic phase on cheese surfaces towards inner layers, with possible degradation;
(d) Increase of microbial spoilage because of the continuous penetration of contaminated aqueous/organic phase;
(e) Possible damage of microcrystalline wax coating because of partial water absorption, including sulphurated amino acids (rotten egg smells) and localised fractures along most curved paraffin walls.

The role of chemistry can be easily extended to the world of physical chemistry. In general, every organic acid may act as a potential antimicrobial substance when considered in the undissociated form (Walstra 2002). Naturally, the theoretical performance of such a substance against microorganisms depends on various factors: concentration of the undissociated acid, temperature, pH, water activity, dissociation constants, and the value of real humidity and the possible presence of different positively-charged species in competition with released protons (Eklund 1983; Krebs et al. 1983; Walstra 2002). For these reasons, the activity of lactates or benzoic acid may be very useful in several situations, while different food applications may show unsatisfactory results.

In addition, the role of water is extremely important: the lower the moisture amount, the lower the inactivation of many microorganisms. More exactly, the value of water activity (A_w) is a limiting factor: normal bacteria can tolerate $0.98 < A_w < 0.90$ with the exception of halophilic life forms (Gould 1989; Mugnier and Jung 1985; Walstra 2002). On the other hand, yeasts cannot tolerate $A_w < 0.9$, except for osmophilic forms, and moulds may tolerate A_w values over 0.8 with the exception of xerophilic moulds (Beuchat 1981, 1983; Mugnier and Jung 1985). The addition of sodium chloride can be used with the aim of lowering A_w (cause: augment of osmotic pressure). Other chemicals—sugars, ethanol, etc.—may be used with the same objective, on condition that targeted life forms are not able to tolerate the desired (added) amount of food additive (Bonadonna et al. 2012; ŌNishi 1963; Stratford 2006; Tokuoka 1993; Walstra 2002).

5.3 The Microbial Risk in Food Industries: Engineering and Food Technology Considerations

The relationship between engineering and microbiology may not appear simple. However, the application of engineering principles in current food processing techniques—including handling, and distribution steps—is probably (Fig. 5.2) one of the main signs of food industrialisation (Drabenstott 1995; Lang 2003).

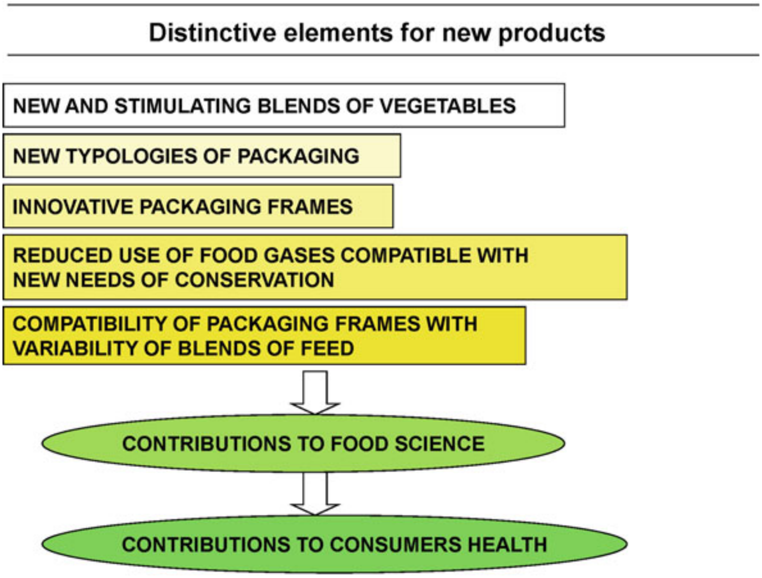


Fig. 5.2 The application of engineering principles in current food processing techniques, including handling, and distribution steps, may be considered one of the main signs of food industrialisation

In detail, process engineers have to support food production techniques by means of the adaptation of mathematical procedures to edible materials (Sun 2005). The presence of engineering in the current food industry is particularly evident in the following innovations (Lang 2003; Sun 2005; Walstra 2002):

- Forming equipment for food production and packaging systems, including vacuum packaging and extrusion (it could be inferred that this process is ‘imported’ from the plastic industry);
- Traditional heating processes (sterilisation, pasteurisation, etc.);
- Food cooling and freezing systems, including new vacuum cooling and high-pressure freezing technologies;
- Non-thermal processing methods (osmotic dehydration, high-pressure processing, pulsed electric fields, ultrasounds, radio-frequency processing, etc.) and machinery (equipments for modified atmosphere packaging systems, etc.);
- Minimal processing for ready-to-eat products (cook and chill, cook and freeze, etc.).

The above-mentioned list is not exhaustive. However, the common point of new technologies is the constant re-development of ‘old’ or traditional systems. The basic aim is the optimisation (reduction) of production times and differences between a produced item and the subsequent one along the working line. At the same time, the use of ‘traditional’ ingredients—such as yeast for breads—or techniques may be omitted, except for hedonistic considerations (Lang 2003).

On the other hand, new systems may give new and unexpected problems in microbial contamination. As a result, process engineers are forced to create or develop adequate countermeasures against ‘old’ but often ubiquitous enemies such as *Listeria monocytogenes*, *Salmonella* spp., *Enterobacteriaceae*, yeasts, moulds, etc. The introduction of modified processes because of food safety considerations must be mentioned in the HACCP plan. In addition, because of the necessity of obtaining ameliorated processing times without the increase of (possible) microbiological risks, the opinion of expert engineers (or maintenance managers) is strictly requested. Practical examples of this activity may be found in selected references (Aguilera and Stanley 1999; Heldman and Lund 2006):

(a) The reduction of thermosealing and extrusion times (forming and/or packaging systems). The basic aim is to reduce the possibility of re-contamination after important treatments such as pasteurisation. In addition, cross-contamination between different working lines or removable parts can be always possible. Finally, the higher the number of produced pieces, the lower the formation of temporary microbial agglomerations during the ‘off-line’ period (the interval between two consecutive parts in the same production step). For these reasons, rheological considerations are often needed because many intermediate foods are fluid matters.

(b) The reduction of freezing times without significant damage to packaged products. Damaged containers undoubtedly lose their main preservation power. Because of the nature of liquid or solid aqueous solutions, the problem of (too) rapid crystallisation remains one of the most challenging concerns at present. The same concern exists with regard to triglyceride crystallisation (Blanshard and Lillford 1987; Garti and Sato 2001; Hartel 2001).

(c) The possible combination of thermal and non-thermal processing methods because of the variability of performance in different foods. For example, the different resistance (survival) of yeasts and vegetative bacteria against pulsed electric fields (Sun 2005).

5.4 The Microbial Risk in Food Industries: Regulatory Norms and Reflections About Information Technology

With regard to HACCP plans and the management of microbiological risks, the role of regulatory norms is obvious. In fact, the microbiological hazard—food-borne outbreaks, localised intoxications, etc.—is probably the most studied and regulated food safety argument worldwide, particularly with reference to the United States of America (USA) and the European Union (EU) (Montanari et al. 2015; Pisanello 2014). In addition, import and export activities towards these economic and politic areas are strictly governed by national authorities based on US and EU norms. Interestingly, the adoption of the HACCP approach and quality systems is one of the main pilasters of the current legislation (Naugle et al. 2005; Ryser and Marth 2007; Unnevehr and Jensen 1999). As a result, the presence of a qualified person with strong knowledge of regulatory obligations should be always recommended to FBO. The recent introduction of new labelling rules in the EU (traceability of food has become the focus of control systems) has substantially strengthened the necessity for regulation-oriented training activities for the HACCP team (Caruso et al. 2015). On the other hand, new obligations have no direct or indirect influence on HACCP plans. However, because of 'hidden implications' (example: modification of recipes and industrial formulations because of the multiplicity of raw materials suppliers), the new Regulation (EU) No 1169/2011 implies also the possible re-evaluation of HACCP plans with regard to all predictable risks. Different raw materials may have different microbial ecologies, after all!

The introduction of new mandatory requirements such as nutritional labelling and traceability information along the food and feed chain has enhanced the role of information technology (IT) in food industries and retail companies (Lang 2003). Actually, software products are very useful when managing considerable quantities of commodities from the logistic viewpoint. On the other hand, the increasing necessity of tracing out all raw materials with some implication on the formulation of food products, including packaging materials, has required new 'just-in-time' solutions. For example, the flow of different raw materials in a dedicated cheese-production line has to be managed step-by-step and continually monitored. Otherwise, certain information on organic foods, genetically modified organisms-free products, special production systems, etc., may be completely lost along the food chain (Moe 1998). These difficulties may be solved in food companies and retail firms by means of adequate wireless or Internet-connected information technology (IT) solutions (Buhr 2003).

In addition, IT products may be very helpful in the practical prediction of microbial spoilage in foods during time. The use of growth and inactivation models such as the Seafood Spoilage and Safety Predictor, the Pathogen Modeling Program or the Food MicroModel are often used and recommended to FBO, although outcomes have to be tested and compared with experimental results (Isabelle and André 2006; McMeekin et al. 2006; Scott 2005). Moreover, other systems can be realised by FBO without expensive software products with the aim of modelling obtained results (Parisi 2001, 2002c, 2004a, b). The simple monitoring of the growth of total coliforms during the production of mozzarella cheeses can be extremely useful on the condition that adequate conditions are respected (Parisi 2010):

(a) Complete and reliable information about raw materials (chemical composition, origin, microbial counts for selected microorganisms, sensorial parameters, etc.);
(b) Exhaustive information about processing steps: number, temperature, need of hot or cold water, pH values, thermal processes, etc.;
(c) Reliable analytical methods with regard to the execution of microbial, chemical and sensorial analyses;
(d) The establishment of a logical schedule for the production of selected lots/batches and the subsequent execution of tests.

It should be also considered that the creation of similar systems can be very difficult in food companies; in addition, obtained results may be true or reliable in certain situations, while predictions may be 'wrong' in other foods. For these reasons, many food technologists may choose simplified approaches. In fact, the compilation of IT solutions for microbiology data should include five different steps (Tamplin et al. 2003); basically, raw data should be organised in a spreadsheet format, adequately interpreted (by human analysts), easily managed and mathematically interpolated. The final step should be (Parisi 2010) the creation of complex predictions such as the answer to the simple question (growth/no growth) for a selected microorganism. As a result, a certain level of knowledge is required for FBO analysts, and IT solutions may not be always simple and available. However, the common element appears to be the necessity of re-evaluation of predicted results (for an ideal pilot plant or in vitro experiments) in the real food or production line (Patriarca et al. 2012).

References

Aguilera JM, Stanley FW (1999) Microstructural principles of food processing and engineering, 2nd edn. Aspen Publishers, Gaithersburg

Armstrong DJ (2009) Food chemistry and US food regulations. J Agric Food Chem 57(18): 8180–8186. doi:10.1021/jf900014h

Artés F, Gómez PA, Artés-Hernández F (2007) Physical, physiological and microbial deterioration of minimally fresh processed fruits and vegetables. Food Sci Technol Int 13(3):177–188. doi:10.1177/1082013207079610

Azanza MPV, Zamora-Luna MBV (2005) Barriers of HACCP team members to guideline adherence. Food Control 16(1):15–22. doi:10.1016/j.foodcont.2003.10.009

Barendsz AW (1998) Food safety and total quality management. Food Control 9(2):163–170. doi:10.1016/S0956-7135(97)00074-1

Beuchat LR (1983) Influence of water activity on growth, metabolic activities and survival of yeasts and molds. J Food Prot 46(2):135–141

Beuchat LR (1981) Microbial stability as affected by water activity. Cereal Foods World 26 (7):345–349

Blanshard JMV, Lillford P (1987) Food behaviour and structure. Academic Press, London

Bonadonna L, Briancesco R, Della Libera S, Paradiso R, Semproni M (2012) Microbial safety of drinking water: assessing and reducing risks. Improved approach and methods. Rapporti ISTISAN 12/1. Istituto Superiore di Sanità, Rome. http://www.iss.it/binary/publ/cont/12_1_web.pdf. Accessed 27 Jan 2015

Branen AL, Davidson PM, Salminen S, Thorngate J (eds) (2001) Food additives. CRC Press, Boca Raton

Buhr BL (2003) Traceability and information technology in the meat supply chain: implications for firm organization and market structure. J Food Distrib Res 34(3):13–26

Caruso G, Barone C, Parisi S (2015) The Regulation (EU) No 1169/2011 and food packaging. New obligations and correlated consequences. Food Pack Bull (in press)

Castle L, Kelly M, Gilbert J (1993) Migration of mineral hydrocarbons into foods. 3. Cheese coatings and temporary casings for skinless sausages. Food Add Contam 10(2):175–184. doi:10.1080/02652039309374141

Coma V, Martial-Gros A, Garreau S, Copinet A, Salin F, Deschamps A (2002) Edible antimicrobial films based on chitosan matrix. J Food Sci 67(3):1162–1169. doi:10.1111/j.1365-2621.2002.tb09470.x

Deasy DJ (2002) Food safety and assurance: the role of information technology. Int J Dairy Technol 55(1):1–4. doi:10.1046/j.1364-727X.2001.00036.x

de Moura MR, Aouada FA, Avena-Bustillos RJ, McHugh TH, Krochta JM, Mattoso LH (2009) Improved barrier and mechanical properties of novel hydroxypropyl methylcellulose edible films with chitosan/tripolyphosphate nanoparticles. J Food Eng 92(4):448–453. doi:10.1016/j.jfoodeng.2008.12.015

Doyle MP, Beuchat LR, Montville TM (eds) (2013) Food microbiology: fundamentals and frontiers. American Society for Microbiology, Washington, DC

Drabenstott M (1995) Agricultural industrialization: implications for economic development and public policy. J Agric Appl Econ 27:13–20

Eklund T (1983) The antimicrobial effect of dissociated and undissociated sorbic acid at different pH levels. J Appl Bacteriol 54(3):383–389. doi:10.1111/j.1365-2672.1983.tb02632.x

Eskin M, Robinson DS (eds) (2000) Food shelf life stability: chemical, biochemical, and microbiological changes. CRC Press, Boca Raton

Garti N, Sato K (eds) (2001) Crystallization processes in fats and lipid systems. Marcel Dekker, New York

Gould GW (1989) Drying, raised osmotic pressure and low water activity. In: Gould GW (ed) Mechanisms of action of food preservation procedures. Elsevier Applied Science, London, pp 97–117

Hartel RW (2001) Crystallization of foods. Aspen Publishers, Gaithersburg

Heldman DR, Lund DB (2006) Handbook of food engineering, 2nd edn. CRC Press, Boca Raton

Holah JT (1992) Industrial monitoring: hygiene in food processing. In: Melo LF, Bott TR, Fletcher M, Capdeville B (eds) Biofilms—science and technology. Kluwer Academic Publishers, Dordrecht, pp 645–659

Holah JT, Higgs C, Robinson S, Worthington D, Spenceley H (1990) A conductance-based surface disinfection test for food hygiene. Lett Appl Microbiol 11(5):255–259. doi:10.1111/j.1472-765X.1990.tb00175.x

Kessler HG (1981) Food engineering and dairy technology. Verlag A. Kessler, Freising

Kilcast D, Subramaniam P (eds) (2000) The stability and shelf-life of food. Woodhead Publishing Limited, Cambridge and CRC Press, Boca Raton

Krebs HA, Wiggins D, Stubbs M, Sols A, Bedoya F (1983) Studies on the mechanism of the antifungal action of benzoate. Biochem J 214:657–663

Isabelle L, André L (2006) Quantitative prediction of microbial behaviour during food processing using an integrated modelling approach: a review. Int J Refrig 29(6):968–984. doi:10.1016/j.ijrefrig.2006.04.008

Johnson RC (2005) Pattern recognition system and method for monitoring hand washing or application of a disinfectant. US Patent 6,970,574

Labuza TP, Fu B (1993) Growth kinetics for shelf-life prediction: theory and practice. J Ind Microbiol 12(3–5):309–323. doi:10.1007/BF01584208

Lang T (2003) Food industrialisation and food power: implications for food governance. Dev Policy Rev 21(5–6):555–568. doi:10.1111/j.1467-8659.2003.00223.x

Lappalainen J, Loikkanen S, Havana M, Karp M, Sjöberg AM, Wirtanen G (2000) Microbial testing methods for detection of residual cleaning agents and disinfectants—prevention of ATP bioluminescence measurement errors in the food industry. J Food Prot 63(2):210–215

McMeekin TA, Baranyi J, Bowman J, Dalgaard P, Kirk M, Ross T, Schmid S, Zwietering MH (2006) Information systems in food safety management. Int J Food Microbiol 112(3):181–194. doi:10.1016/j.ijfoodmicro.2006.04.048

Moe T (1998) Perspectives on traceability in food manufacture. Trends Food Sci Technol 9(5):211–214. doi:10.1016/S0924-2244(98)00037-5

Montanari F, Jezsó V, Donati C (2015) Risk regulation in non-animal food imports. The European Union Approach. SpringerBriefs in Chemistry of Foods, Springer, Heidelberg (in press)

Mortimore S, Wallace C (2013) HACCP: a practical approach. Aspen Publishers, Gaithersburg

Mugnier J, Jung G (1985) Survival of bacteria and fungi in relation to water activity and the solvent properties of water in biopolymer gels. Appl Env Microbiol 50(1):108–114

Naugle AL, Holt KG, Levine P, Eckel R (2005) Food safety and inspection service regulatory testing program for Escherichia coli O157: H7 in raw ground beef. J Food Prot 68(3):462–468

Ozdemir M, Floros JD (2004) Active food packaging technologies. Crit Rev Food Sci Nutr 44(3):185–193. doi:10.1080/10408690490441578

ŌNishi H (1963) Osmophilic yeasts. Adv Food Res 12:53–94. doi:10.1016/S0065-2628(08)60006-3

Pagán-Rodríguez D, O'Keefe M, Deyrup C, Zervos P, Walker H, Thaler A (2007) Cadmium and lead residue control in a hazard analysis and critical control point (HACCP) environment. J Agric Food Chem 55(4):1638–1642. doi:10.1021/jf062979z

Panfiloiu M, Cara MC, Perju DM, Dumitrel GA (2011) Quality control of pastry products using the HACCP method. Chem Bull 'POLITEHNICA' Univ (Timisoara) 56(70):47–51. http://chemicalbulletin.ro/admin/articole/77021art_10_47-51_pdf. Accessed 16 Jan 2015

Parish ME, Beuchat LR, Suslow TV, Harris LJ, Garrett EH, Farber JN, Busta FF (2003) Methods to reduce/eliminate pathogens from fresh and fresh-cut produce. Compr Rev Food Sci Food Saf 2(s1):161–173. doi:10.1111/j.1541-4337.2003.tb00033.x

Parisi S (2001) Profili evolutivi dei contenuti microbici in prodotti lattiero-caseari. Records Book of the Tenth National Conference 'I rischi microbiologici del 2000 nel settore alimentare', pp 105–110. Chiriotti Editori, Pinerolo

Parisi S (2002a) Profili evolutivi dei contenuti batterici e chimico-fisici in prodotti lattiero-caseari. Ind Aliment 412:295–306

Parisi S (2002b) I fondamenti del calcolo della data di scadenza degli alimenti: principi ed applicazioni. Ind Aliment 417:905–919

Parisi S (2002c) Applicazioni della chemiometria nel campo dei prodotti lattiero-caseari. Ind Aliment 422:129–133

Parisi S (2003a) Il packaging alimentare: definizioni, caratteristiche essenziali, influenza sulla qualità degli alimenti confezionati. Second Level University Master in Food Hygiene and Food Legislation, University of Messina, Italy

Parisi S (2003b) La previsione della minima durabilità degli alimenti: principi fondamentali ed applicazioni pratiche. Second Level University Master in Food Hygiene and Food Legislation, University of Messina, Italy

Parisi S (2004a) Logarithmic growth of non-lactic bacteria in dairy products. Italy Food Technol 35:1–7

Parisi S (2004b) Alterazioni in imballaggi metallici termicamente processati. Gulotta Press, Palermo

Parisi S (2009) Intelligent packaging for the food industry. In: Gardiner FL, Carter EJ (eds) Polymer electronics: a flexible technology. Smithers Rapra Technology Ltd, Shawbury

Parisi S (2010) HACCP Assessment: studio di nuovi piani di campionamento in forma ridotta nel campo lattiero-caseario. Dissertation, University of Messina

Parker R, Ring SG (2001) Aspects of the physical chemistry of starch. J Cereal Sci 34(1):1–17. doi:10.1006/jcrs.2000.0402

Patriarca V, Di Bartolo I, Tozzoli R, Aquimi U (2012) Argomenti di Sanità Pubblica Veterinaria e Sicurezza Alimentare. Seminari dipartimentali 2011. Rapporti ISTISAN 12/54. Istituto Superiore di Sanità, Rome

Pisanello D (2014) Chemistry of foods: EU legal and regulatory approaches. SpringerBriefs in Chemistry of Foods, Springer, Heidelberg

Rigarlsford JF (2006) Microbiological monitoring of cleaning and disinfection in food plants. In: Mead GC (ed) Microbiological analysis of red meat, poultry and eggs. Woodhead Publishing Limited, Cambridge and CRC Press, Boca Raton

Roberto CD, Brandão SCC, Barbosa da Silva CA (2006) Costs and investments of implementing and maintaining HACCP in a pasteurized milk plant. Food Control 17(8):599–603. doi:10.1016/j.foodcont.2004.05.011

Ryser ET, Marth EH (eds) (2007) Listeria, listeriosis, and food safety. CRC Press, Boca Raton

Schmidt RH (1997) Basic elements of equipment cleaning and sanitizing in food processing and handling operations. Fact Sheet FS-14, University of Florida, Institute of Food and Agriculture Sciences, Cooperative Extension Service. http://www.us.rexroth.com/country_units/america/united_states/sub_websites/brus_packaging_processing/en/a_downloads/UF_equipmentcleaning.pdf. Accessed 17 Jan 2015

Scott VN (2005) How does industry validate elements of HACCP plans? Food Control 16(6):497–503. doi:10.1016/j.foodcont.2003.11.013

Singh RP, Heldman DR (1993) Introduction to food engineering, 2nd edn. Academic Press, San Diego

Stilo A, Parisi S, Delia S, Anastasi F, Bruno G, Laganà P (2009) Food security in Europe: comparison between the “Hygiene Package” and the British Retail Consortium (BRC) & International Food Standard (IFS) protocols. Ann Ig 21(4):387–401

Stratford M (2006) Food and beverage spoilage yeasts. In: Amparo Q, Fleet G (eds) Yeasts in food and beverages. Springer, Berlin, pp 335–379

Sun DW (ed) (2005) Emerging technologies for food processing. Elsevier Academic Press, San Diego

Tamplin M, Baranyi J, Paoli G (2003) Software programs to increase the utility of predictive microbiology information. In: McKellar RC, Lu X (eds) Modelling microbial responses in foods. CRC Press, Boca Raton, pp 233–242

Tokuoka K (1993) Sugar-and salt-tolerant yeasts. J Appl Bacteriol 74(2):101–110. doi:10.1111/j.1365-2672.1993.tb03002.x

Unnevehr LJ, Jensen HH (1999) The economic implications of using HACCP as a food safety regulatory standard. Food Policy 24(6):625–635. doi:10.1016/S0306-9192(99)00074-3

Walstra P (2002) Physical chemistry of foods. CRC Press, Boca Raton

Chapter 6
The Chemistry of Disinfection: Ally or Enemy?

Abstract This chapter is specifically dedicated to the problem of sanitisation in food industries. The term ‘sanitisation’ can be easily confused with ‘disinfection’ depending on the ‘subject’ of the desired treatment. In general, sanitisation or sanitation is the use of one (or more) system or chemical substance on surfaces of equipment or utensils with the aim of destroying disease causing microorganisms. On the other hand, the disinfection may be also applied to water for food and non-food applications. With regard to food-contact surfaces, cleaning and disinfection procedures should follow a clear two-step sequence. The first step corresponds to the preliminary cleaning (three sub-steps: manual removal of loose materials; chemical cleaning and final rinsing with water). The second step is the true sanitising step. The role of chemicals as cleaning agents (first step) and sanitising compounds is described in this chapter with correlated risks, except for chlorine compounds.

Keywords Chemical cleaning · Disinfection · Food business operator · HACCP · Sanitising agent · Sterilisation

6.1 Disinfection in Food Industries: Needs and Solutions

The limitation or the eradication, where possible, of microbial risks in food industries and correlated plants (including also warehouses in shopping centres, trucks, etc.) is one of the most important challenges at present (Sect. 1.5). The creation and the reliable implementation of adequate systems in accordance with the so-called ‘Hazard Analysis and Critical Control Points’ (HACCP) strategy are the best answers and the only possibility at present. Basically, microbiological risk may be reduced by means of the following techniques and/or procedures (Evans et al. 2004; Ropkins and Beck 2000; Scott and Bloomfield 1990):

(1) Correct selection of raw ingredients and packaging materials;
(2) Separation between different areas;

G. Gurnari, *Safety Protocols in the Food Industry and Emerging Concerns*,
Chemistry of Foods, DOI 10.1007/978-3-319-16492-2_6

(3) Prevention of cross-contamination episodes between different lines dedicated to the production of dissimilar foods;
(4) Prevention of survival and transfer of microscopic life forms via cloths, hand wheel lifters and utensils;
(5) Prevention of microbial contamination by food refrigeration equipment;
(6) Use of thermal processing treatments and preserving technologies (smoking, salting, etc.);
(7) Use of purified water and modern techniques (sonication, etc.);
(8) Purification of atmospheric gases and prevention of aerosolised suspensions;
(9) Control of environmental parameters and air treatment systems;
(10) Choice of suitable products for chemical or physical treatment, possibly with official quality certification;
(11) Creation and implementation of correct cleaning and sanitising procedures.

The basic aim of food technologists is the creation of a reliable production flow with the following features:

(a) Minimisation of product-related failures caused by productive delays, excessive offline interruption of processes, insufficient or lack of supply of raw materials, technological problems such as rheological differences between different sections of the same intermediate mass into production lines, etc.
(b) Reduction of food safety failures caused by use of contaminated raw materials and/or intermediates in the productive flow, insufficient or lacking cleaning and/or disinfection of working lines and processing machinery, aerosol suspensions of spoilage microorganism, use of contaminated water for different applications (including also the simple ‘solvent’ function for water-soluble raw foods), etc.
(c) Elimination or limitation of dangerous chemical residues in foods and food processing lines (different causes).

The above-mentioned list is inexhaustive; many different problems may occur at the same time because of concomitant causes. In addition, it can be inferred that different food safety failures are systemic (Hennessy et al. 2003). For this reason, the prediction of food hygiene problems may be obtained by means of systems analysis methods such as modelling tools.

This chapter is dedicated to the problem of sanitisation in food industries. The term ‘sanitisation’ can be easily confused with ‘disinfection’, depending on the ‘subject’ of the desired treatment. Therefore, a short premise should be made with reference to the meaning of these words.

In general, sanitisation or sanitation is the use of one or more systems or chemical substances on the (clean) surface of equipment or utensils with the aim of destroying disease causing microorganisms (Stanfield 2003). In addition, the reduction of spoilage microorganisms without pathogenic activity is highly recommended and desired. Finally, it should be considered that sanitising agents must be used after careful cleaning of surfaces. In other words, ‘dirty’ surfaces cannot be sanitised. The same may be in the case of ‘hard water’ (high presence of calcium and magnesium salts) with regard to water for cleaning purposes: the greater the water hardness, the lower the reliability of the cleaning process.

On the other hand, disinfection may be also applied to water for food and non-food applications (Parisi 2006). Possible situations can be the simple washing of food processing lines or the addition to food formulations as an edible ingredient (cheeses are one of the most known examples).

With regard to water and correlated contamination risks, the main environmental sources of microbial contamination are recognised as follows (Kirby et al. 2003; Sivapalasingam et al. 2004; Slifko et al. 2000):

- Water intended for primary production facilities;
- Water intended for food processing plants and operations;
- Recycled water;
- Feeding products intended for animal nutrition;
- Contaminated air (aerosolised suspensions, excess or unwanted elements such as sulphur, nitrogen and carbon, complex molecules, etc.);
- Other causes, including hygienic conditions of factory workers.

With regard to water supplies for food production, normal treatments (with the exclusion of wastewater) concern the following operations (Kirby et al. 2003; WHO 1996):

(a) Coagulation;
(b) Sedimentation;
(c) Filtration;
(d) Other advanced treatments (activated carbon, ion exchange, membrane filtration, reverse osmosis, etc.);
(e) Final disinfection (oxidation, ultraviolet light, heating processes, use of caustic substances, etc.).

The common point appears to be the use of different chemicals as sanitisers. With regard to used or recycled water in food plants, food business operators (FBO) can reasonably use a few selected methods among these systems (Bintsis et al. 2000; Casani et al. 2005; Kirby et al. 2003):

- Sedimentation and filtration;
- Ion exchange;
- Ultraviolet (UV) light;
- Reverse osmosis;
- Membrane filtration;
- Lime treatment;
- Flocculation with selected aid such as Guar gums (with regard to chemical purification);
- Complete disinfection (oxidising chemicals, UV light, caustic chemicals, heating processes, etc.);
- Innovative systems: electrolysed water, ozonisation, synergic ozonisation and ultraviolet light treatment, etc.

Once more, the use of chemicals or chemical processes is clear enough with regard to water treatments. Moreover, the sanitisation of (clean) surfaces is mainly carried out in a similar manner with the inclusion of different chemicals. The next section is dedicated to the description of the main chemical cleaners, sanitisers and disinfecting agents for food processing surfaces.

6.2 Main Chemicals for Food Cleaning and Disinfection

6.2.1 Cleaning Chemicals

The disinfection of food-contact surfaces cannot be obtained without preliminary cleaning, which may be carried out in three steps (Stanfield 2003):

(1) Manual removal of loose materials. This simple but extremely important operation may be performed by flushing dirty surfaces with cold or warm potable water under pressure.
(2) Chemical cleaning with specific products and related devices.
(3) Final rinsing with water. In this step, the use of hot water may be recommended because of the necessity for decreasing drying times before the application of the final sanitiser.

The second step can be performed in four different ways (Stanfield 2003):

(a) Soaking systems: Small machines are required. The use of hot cleaning solutions, including pre-dissolved mixtures, is necessary. After 15–30 min, cleaning solutions on surfaces have to be manually or mechanically removed.
(b) Spray systems: Cleaning solutions are sprayed on surfaces with hot water or steam.
(c) Abrasive procedures: Sometimes, the removal of difficult agglomerations (soil) may require the use of abrasive powders or similar substances. On the other hand, this method may be dangerous because of the possible removal of stainless steel surfaces.
(d) Clean-in-place (CIP) systems: These procedures imply the use of highly automated machines with the necessary presence of welded pipelines. The distribution of cleaning solutions on surfaces can be very useful in conjunction with an adequate fluid turbulence.
(e) Clean-off-place (COP) procedures: In other words, food processing surfaces may be cleaned by means of manual systems or COP-automated machines such as pressure jet, foam or dry ice methods.
(f) Other systems: washing-in-place (WIP) procedures. Generally, these systems are used for reusable containers.

The following four factors should be considered carefully for cleaning procedures:

- Chemical type of cleaning agent;
- Concentrations of cleaning compounds;
- Mechanic features of the used system (examples: pressure, velocity)
- Temperature and time of application;
- Energy and environmental costs.

Generally, cleaning solutions are complex mixtures of different t substances. The reason for a similar formulation depends on the nature of soils on 'dirty' surfaces, the type of food-contact surface and the expected physical–chemical action of cleaning solutions (Anonymous 2002).

From the chemical viewpoint, five main components may constitute normal soils on food-contact surfaces for processing machinery:

- Fats
- Sugars
- Proteins
- Monovalent salts
- Polyvalent salts

In general, soils can be easily removed of sugars and monovalent salts because these compounds are water-soluble (monovalent salts may also be dissolved in acid solutions). On the other hand, it should be remembered that heating treatments (or the use of hot water) may cause the partial caramelisation of carbohydrates. Thus, hot water is not recommended.

Protein soils are difficult to clean because of their known insolubility in water, while acid solutions may be partially useful. In addition, proteins can denatured with the modification of their physical and chemical features. For these reasons, the best strategy is the (moderate) use of alkaline substances because of their high corrosion power.

Removing of fats and polyvalent salts may be easier compared with cleaning of protein soils. In fact, fat molecules and aggregations can be dissolved in alkaline solutions (the problem may be the polymerisation), while polyvalent salts such as calcium tri-phosphate can be removed with some difficulty by means of acid solutions.

The type of food-contact surfaces has to be taken into account. The most known and used materials are:

(a) (Polished) stainless steel;
(b) Aluminium;
(c) Plastics (high-density polymers);
(d) Coated surfaces (coatings: polytetrafluoroethylene, etc.);
(e) Wood (low porosity, high specific gravity);
(f) Marble.

As a consequence, cleaning substances should be carefully chosen on the basis of the resistance of either soils or surfaces.

Finally, the chemical and physical action of cleaning (detergent) agents should be evaluated. In general, the composition of these agents includes the following ‘active principles’:

- Acid chemicals
- Alkaline substances
- Chelating compounds
- Surfactants
- Complex phosphates
- Other oxidants (quaternary, etc.).

Acids are mainly used when the desired reaction is the saponification of fatty molecules. In addition, mild-force acids may be useful for dispersing soil particles. On the other hand, these compounds may moderately corrode. It has to be considered that strong acids are a better choice for saponification and peptisation of protein agglomerations, but their corrosion power is remarkable. As a result, these compounds have to be carefully evaluated before use (anytime).

Alkaline substances can be used when the desired reactions are saponification and peptisation. Moreover, rinsing operations are easier. On the other hand, the use of alkaline solutions is probably the worst choice in superficial damages (high corrosion power).

As a result, chelating agents (polyphosphates, etc.) and surfactants are highly recommended in the food industry because of their virtual absence of damages on surfaces. Naturally, the difference between chelating agents and surfactants is correlated to the complex effect on cations (on the one hand) and remarkable features such as wetting, rinsing and emulsifying power on the other hand.

From the chemical viewpoint, the above-mentioned five classes of cleaning agents may be discussed as follows.

6.2.1.1 Acid Cleaning Agents

The group of acid cleaning agents is well known in the food industry because of the massive use on food processing surfaces with notable mineral encrustations such as ‘beer stone’ and ‘milk stone’ (Arrington 1991; Porter 1972). For example, the so-called ‘milk stone’ (Gilmore 1935; Hamid et al. 2013), commonly defined as the typical contamination of food surfaces in milk plants, has variable composition and physical properties depending on factors such as temperature of cleaning processes, water hardness, classification of milk-producing animals, type of metallic surface, possibility of ‘high-temperature short-time’ pasteurisation systems, etc. (Boxler et al. 2014; Leeder 1956; Stanga 2010). In general, it may be assumed that milk stone encrustations should be composed mainly of water, proteins, organic molecules, mineral substances (calcium phosphate, etc.) and fats (Boxler et al. 2014; Du Plessis 2012; Hamid et al. 2013), while carbohydrates (lactose) are virtually absent. In addition, microbiological contamination by moulds is associated with milk stone deposits. As a consequence, the removal of such a complex soil is absolutely necessary.

The use of alkaline detergents is not recommended with regard to milk stone because of the production of yellow-whitish grains on surfaces of jars and correlated valves, in spite of the remarkable concentration of strong chelating molecules such as ethylenediaminetetraacetic acid (EDTA). The continuous accumulation of milk stone deposits on surfaces, cleaning after cleaning, is detrimental: the resulting encrustation assumes exceptional hardness. For this reason, acid cleaners are recommended (Stanga 2010). On the other hand, a different strategy may be tried with good results from the viewpoint of food safety. In fact, mould contamination is favoured on milk stone deposits because of the formation of strong connections to surfaces by means of glycol-protein materials and the necessary presence of metals (Stanga 2010). In these situations, the use of active chlorine after alkaline removal may be useful because of the destruction of chemical connections between moulds and surfaces. In other words, milk stone may be removed because of the presence of moulds.

With regard to acid cleaners, the strategy should comprise two steps: first, the use of acid solutions. From the chemical viewpoint, acid cleaners should be mixtures of organic and inorganic acids with non-ionic wetting agents (Chmielewski and Frank 2003); it has to be considered that the used solution should reach very low pH values. Naturally, the real disadvantage of such a system is represented by corrosion risks.

Generally, most used acid substances for formulation of acid cleaners are:

(a) Organic acids (Fig. 6.1) such as hydroxyacetic, acetic, lactic, citric, glycolic, tartaric; formic, gluconic acids; phosphonic acids and
(b) inorganic acids such as sulphuric, nitric, muriatic, sulphamic, sodium acid sulphate, hydrochloric acids.

Wetting agents are also important because of their emulsifying and foaming power (Chmielewski and Frank 2003). In addition, a certain amount of sequestrant or chelating agents such as sodium phosphate derivatives may be required

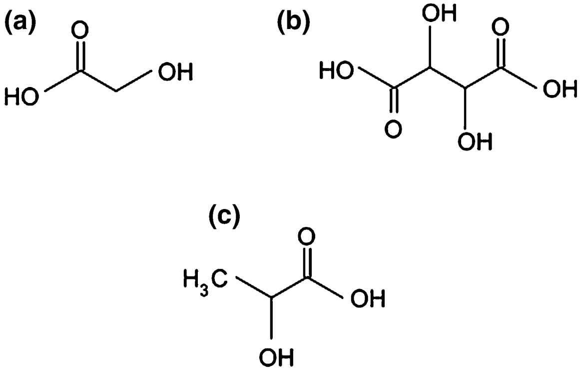


Fig. 6.1 Cleaning compounds: organic acids. This figure shows the chemical structure of hydroxyacetic (**a**), gluconic (**b**) and lactic (**c**) acids

(Chmielewski and Frank 2003). However, the most useful feature of the final cleaning solution is often represented by water. Should this water contain calcium, magnesium, iron or other ions in a remarkable amount, cleaning performances would be insufficient (Anonymous 2002). For this reason, water has to be treated with the aim of removing mineral content in excess. Alternatively, the cleaning agent should be modified. The final result of cleaning after rinsing is directly correlated to the used water because of the possible precipitation of mineral salts in alkaline conditions. In summary, waters should have pH ≤ 6.5 (Anonymous 2002).

6.2.1.2 Alkaline Cleaning Agents and Complex Phosphates

Generally, alkaline detergents are classified in function of their cleaning power. With regard to alkaline mixtures, the most powerful substances are (Schmidt 1997):

(a) Sodium hydroxide; potassium hydroxide whose main applications are in CIP and WIP systems.
(b) Salt of phosphates, carbonates and silicates (cations: sodium, potassium and ammonium). Interestingly, silicate may be also used because of its anti-corrosion features, while carbonates may be recommended in several situations only because of the possible interaction with calcium and magnesium.

6.2.1.3 Surfactants

Good cleaning agents should contain a certain amount of sequestrant, chelating and surfactant agents. With regard to the last group of chemical substances, two different chemical sub-groups are available on the market; as a result, the final performance of cleaning solutions depends on the use of one surfactant type or another. For this reason, different surfactants are often mixed. The usual classification considers (Schmidt 1997):

(a) Ionic surfactants: These molecules, positively or negatively charged in water solutions (cationic surfactants at acid pH values; anionic surfactants in alkaline conditions), are widely used when a certain foaming effect is desired
(b) Non-ionic surfactants: These compounds do not dissociate in anionic and cationic particles when dissolved in water. Interestingly, these compounds may be blended without precipitation problems, differently from ionic surfactants.

6.2.1.4 Chelating and Sequestrant Agents

With regard to cleaning procedures, the dilution of the original mixture in water is critical. As mentioned above, water hardness may be a huge concern. For this reason, two different classes of chemical compounds are mixed with acid/alkaline agents and surfactants with the aim of preventing the precipitation of various calcium and magnesium salts. The most important and used chelating agents are EDTA and sodium gluconate, while sequestrant molecules are generally polyelectrolytes, organophosphates, etc.

6.2.1.5 Cleaning Mixtures: Minor Components

The composition of cleaning mixtures may include other interesting chemicals with different functions. Two of the main sub-classes of 'minor' components are (Chmielewski and Frank 2003):

(1) Enzymes (simple amylases, proteases and lipases): Apparently, the use of such a component in cleaning solutions may destroy undesired soils without excessive damage to surfaces. In addition, these substances are often defined as 'environmentally-friendly' chemicals.
(2) Oxidisers: These chemicals—sodium perborate and hypochlorite, chlorinated agents, etc.—may be used with the aim of enhancing the power of cleaning solutions.

6.2.2 Sanitising Chemicals

The final step of cleaning and sanitising operations in food plants corresponds to the true 'sanitisation'. This operation has to be carried out carefully because of the necessity of eradicating pathogen agents (and reducing the microbial count of spoilage microorganisms) without subsequent treatments. In general, all possible food processes—cooling, cutting, defatting, drying, extruding, inspecting, shredding, washing, forming, etc.—are concerned (Stanfield 2003).

A short premise should be done with regard to three different terms that can be easily confused are sterilisation, disinfection and sanitisation or sanitation (Schmidt 1997).

Sterilisation concerns all possible methods for the complete destruction and removal of life forms (Ball 1938; Dempsey and Thirucote 1988; Schmidt 1997; Xavier 1999). On the other hand, 'disinfection' can be easily confused with sterilisation and 'sanitisation' in spite of the clear meaning of destruction of vegetative cells with the exclusion of spore-forming microorganisms (Block 2001; Codex Alimentarius Commission 2003; Schmidt 1997).

Actually, the term 'sanitisation' refers only to all methods that can assure the reduction of microbial levels to low and safe concentrations from the viewpoint of food hygienists (Schmidt 1997). As a result, the differentiation between the above-mentioned and apparently similar terms is extremely useful because of the different level of intended safety.

From the microbiological viewpoint, the reliable sanitisation for food-contact surfaces should guarantee at least a 5 log—reduction of microbial numbers in 30s, in accordance with the Association of Official Analytical Chemists (AOAC) Method 960.09 (Roselle et al. 2004; Rovison et al. 2007; Schmidt 1997). All possible systems with such a performance can be defined as 'sanitising' treatments. Generally, two categories of processes are recognised with this term: thermal treatments (use of high temperatures by means of hot water or steam) and chemical procedures (Schmidt 1997).

With regard to the basic aim of this book, chemical treatments are discussed as the logical pursuance of industrial cleaning and sanitising methods. It has to be remembered that chemical sanitisers cannot (Schmidt 1997; Schmidt and Erickson 2008; Stanfield 2003):

(a) Destroy, corrode, stain or leave undesired films on treated surfaces;
(b) Be toxic for human consumption (in other words: they have to be food-contact approved);
(c) Be dangerous for use (into food plants).

Moreover, chemical sanitisers should (Lawley et al. 2012; Richter and Cords 2001; Rossoni and Gaylarde 2000; Schmidt 1997):

- Have a very large action spectrum against life forms;
- Be very stable under particular conditions (examples: hot temperatures, long periods of contact with cleaned surfaces, etc.);
- Be dissolved (in water) in a very limited time.

Finally, the real performance of sanitising chemicals may be also dependent on non-chemical features of the process. Substantially, the following factors can reduce the effective power of chemical sanitisers:

(1) Absence of superficial cracks, microfractures or other surface irregularities, including also uncleaned milkstone or beerstone deposits, etc. (Schmidt 1997; Stanfield 2003).
(2) The temperature of use: In spite of the clear kinetic correlation between high temperatures and the more efficient reduction of living organisms, the application of hot sanitising solutions on 'vulnerable' surfaces may give undesired results such as the corrosion of metal supports (or the destruction of coating materials). For this reason, a maximum limit of 55 °C is recommended (Castillo et al. 1999; Dickson et al. 1994; Gorman et al. 1995; Schmidt 1997).
(3) The concentration of sanitisers: Generally, excessive amounts do not give ameliorated results. For this reason, the concentration should not be augmented (Schmidt 1997).
(4) pH values of the final solution (generally, 7.5 is considered the most tolerated value).
(5) Cleaning traces (Schmidt 1997).
(6) Peculiar life forms (Flint et al. 1997; Lindsay and Von Holy 1999; Lindsay et al. 2002) with enhanced resistance against certain sanitisers (*Escherichia*

coli and *Staphylococcus aureus* are currently used to assess the efficacy of sanitisers in accordance with AOAC 960.09).

After this premise, the chemical composition of different chemical sanitisers may be discussed. The list of the most common products includes the following chemicals (Schmidt 1997; Stanfield 2003):

(1) Inorganic chlorine products (liquid chlorine, sodium hypochlorite, inorganic chloramines, etc.);
(2) Organic chlorine products and other chlorine compounds (chlorine dioxide);
(3) Iodine and iodophores;
(4) Acid-anionic sanitisers;
(5) Fatty acid sanitisers;
(6) Quaternary ammonium salts;
(7) Peroxides;
(8) Synthetic phenols;
(9) Ozone.

6.2.2.1 Chemical Sanitisers: Chlorine-Based Chemicals, Including Chlorine Dioxide

Chlorine is well known and extensively used because of the following features (Anonymous 2002; Schmidt 1997):

(a) This molecular species is a wide action germicide; microbial membranes, deoxyribonucleic acid chains and cellular proteins are reported to be heavily damaged by chlorine;
(b) The germicide action is demonstrated at low temperatures also;
(c) Chlorine does not leave residues on treated surfaces;
(d) Water hardness does not seem to reduce the germicide power of chlorine;
(e) Chlorine releasing compounds are not expensive, compared with other sanitisers.

Generally, inorganic chlorine (liquid chlorine, sodium hypochlorite, inorganic chloramines, etc.) and organic compounds can release hypochlorous acid and hypochlorite, when dissolved in water (McGlynn W 2013). On the other hand, several problems can occur when chlorine is used. It has to be remembered that chlorine activity may be reduced in certain situations, which are as follows (Schmidt 1997):

(1) The real amount of active and available chlorine depends strictly on pH;
(2) The concentration and exposure times may vary depending on the used species. The recommended amount of available chlorine for food-contact surfaces cleaning and process water should be (Anonymous 2002; Gil et al. 2009; Wang et al. 2004) 100 parts per million (ppm), although 200 ppm has been also reported with 1–2 min contact time (Parish et al. 2003).

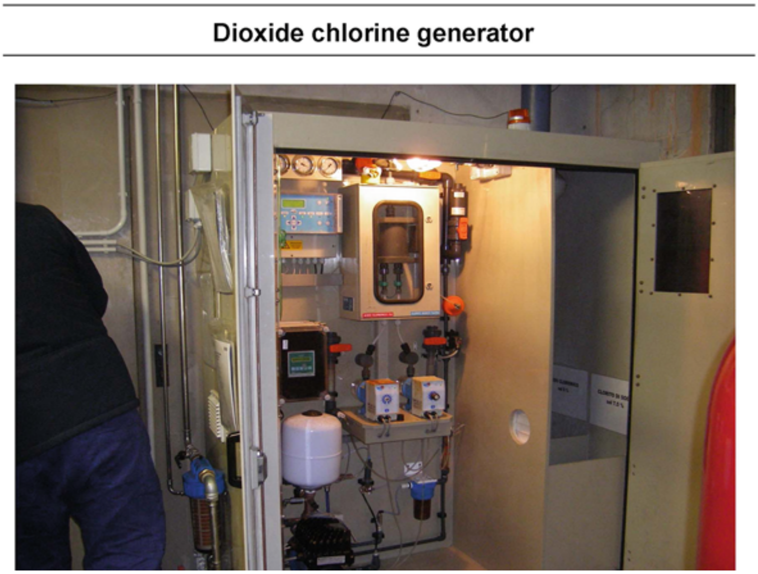


Fig. 6.2 Several problems can occur when inorganic and organic chlorine products are used in food industries. In addition, chlorine activity may be reduced in certain situations. The use of different strategies such as chlorine dioxide generation may be recommended. In particular, ClO_2 is reported to be more efficient than other chlorine-based sanitisers with regard to oxidising power

In addition, the use of chlorine in food industries is of concern (Chap. 7) because of different problems, including the known irritating sensation to skin and mucosae membranes (Anonymous 2002).

For these reasons, the use of different sanitisers such as chlorine dioxide (ClO_2) may be recommended (Schmidt 1997). In particular, ClO_2 is reported to be more efficient than other chlorine-based sanitisers when speaking of oxidising power (Fig. 6.2). Consequently, a minor amount may be required (maximum value: 10 ppm).

It is necessary to remember that the use of chlorine in water determines the possibility of formation of chlorine derivatives, some of which are very toxic (for example halomethanes, etc.).

6.2.2.2 Chemical Sanitisers: Iodine and Iodophores

Similar to chlorine, iodine is reported to have good germicide power because of the possible halogenation of proteins and the destruction of enzymes in microbial cells (Schmidt 1997). However, this sanitising agent has to be carefully evaluated before use because of the following features:

(1) The most active form, dissociated free iodine, is unstable and dependent on pH values (the lower the pH, the higher the concentration). In addition, the higher the environmental temperature, the higher the evaporation of iodine;
(2) Moreover, iodine is not easily soluble in water. For this reason, iodine can be used in association with surfactants. The resulting mixture is called 'iodophore';
(3) Iodine is considered highly toxic when ingested;
(4) Finally, plastic surfaces may be stained when iodine compounds are used.

On the other hand, iodine may be positively judged with reference to wide spectrum-germicide action and the reduced influence of impurities (organic particles, carbonates) in water (Schmidt 1997). Moreover, iodophores are generally reported to be non-corrosive and non-irritating agents on skin (Anonymous 2002). Interestingly, the amber colour of dissolved iodophores in water can be a distinctive advantage with regard to the simple colorimetric (visual) control of concentrations to skin (Anonymous 2002). Naturally, the concentration of available iodine is also important; the recommended quantity is reported to be 30 ppm to skin (Anonymous 2002).

6.2.2.3 Chemical Sanitisers: Acid-Anionic Sanitisers

Acid-anionic sanitisers should be considered as mixtures or inorganic acids and surfactants. In general, these negatively charged compounds are used because of the following features (Schmidt 1997):

(1) Good chemical stability;
(2) Acceptable cleaning power;
(3) Low smell release;
(4) Absence of corrosive effects.

On the other hand, these sanitisers may be very expensive. In addition, the germicide power is reported to be dependent on pH values (between 2 and 3), without effective results against moulds and spore-forming organisms on skin (Anonymous 2002). Finally, acid-anionic sanitisers appear incompatible with cationic surfactants. For these reasons, the use of these sanitisers is quite limited at present on skin (Anonymous 2002). The recommended amount of available acid-anionic sanitisers is reported to be approximately 200 ppm to skin (Anonymous 2002).

6.2.2.4 Chemical Sanitisers: Fatty Acid Sanitisers

Fatty acid sanitisers are interesting compared with acid-anionic compounds. Chemically, they are mixtures of fatty acids and other acid substances. These agents are reported to be highly stable (Schmidt 1997) and cause low foam effects (this failure is typical for acid-anionic sanitisers). On the other hand, germicide activity is reduced if $pH > 3.5$. Finally, corrosiveness is reported when using these substances on plastic surfaces (Schmidt 1997).

6.2.2.5 Chemical Sanitisers: Quaternary Ammonium Salts

Chemically speaking, quaternary ammonium salts are positively charged cations with the main contribution of nitrogen, while four alkyl groups can justify the positive charge (Fig. 6.3). These compounds are reported to be highly stable, more active at higher pH values, less affected by water hardness compared with other sanitisers (Schmidt 1997).

In addition, the lower the length and the number of carbon units on alkyl chains, the higher the solubility in water and the general germicide power. Interestingly, quaternary ammonium salts are highly recommended because of the release, after sanitisation, of residues with antimicrobial activity (Schmidt 1997). However, this advantage can negatively influence monitoring activities with possible concerns (Anonymous 2002; Parisi 2002).

Finally, quaternary ammonium salts may also be used for production of food-safe room deodorisers and/or fogging agents (Schmidt 1997). At present, the recommended amount of available quaternary ammonium salts is reported to be approximately 450 ppm (Anonymous 2002).

6.2.2.6 Chemical Sanitisers: Peroxides

Peroxides are considered high power-germicidal agents because of the creation of oxidising environments by means of the singlet oxygen particle (Hubig et al. 2004; Juven and Pierson 1996; Schmidt 1997). It can be assumed that peroxides are active against Gram-positive and Gram-negative bacteria with similar performances (Schmidt 1997).

This group of chemical sanitisers is subdivided into two sub-classes: inorganic peroxides—hydrogen peroxide—and organic molecules, including peroxyacetic acid.

The application of hydrogen peroxide in food production environments is not generally recommended because this agent may be very dangerous for operators when its concentration is 5 % at least (Schmidt 1997).

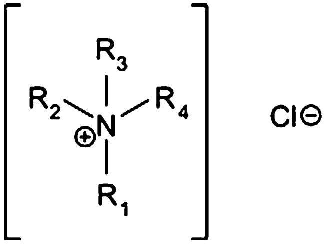


Fig. 6.3 Sanitising compounds: the general structure of quaternary ammonium salts. R_1, R_2, R_3 and R_4 are four different fragments, while the negative chloride ion may be also a common halogen atom. The *lower* the length and the number of carbon units on alkyl chains, the *higher* the solubility in water and the general germicide power

On the other hand, peroxyacetic acid appears as the best strategy because of the following advantages:

(a) Acceptable stability;
(b) Medium corrosion risks (depending on the contact time);
(c) Interesting 'environmental-friendly' features such as biodegradability.

The germicide power of peroxyacetic acid may be dependent on pH values: the maximum value for acceptable results is reported to be 7.0 (Schmidt 1997). Another unsatisfactory feature is correlated to the high oxidising power; similar to hydrogen peroxide, peroxyacetic acid is toxic and a potential corrosive agent (Cords and Dychdala 2003; Schmidt 1997).

6.2.2.7 Other Chemical Sanitisers

Synthetic phenols can be used as powerful sanitisers in the food industry because of the following positive features (Anonymous 2002):

(1) Wide spectrum of germicide action, with the exclusion of spore-forming organisms and
(2) good stability in water.

In addition, germicide action is not reduced in presence of residue soils and hard waters. On the other hand, these substances may release residual films on treated surfaces similar to quaternary ammonium compounds. Moreover, synthetic phenols are reported to be irritating agents and able to release undesirable odours (Anonymous 2002).

Ozone may also be very useful; however, the use of such a sanitiser is limited to waters only and washing operations in the industry of vegetable products (Pascual et al. 2007). In general, ozone is reported to show a wide spectrum action against bacteria, viruses and spore-forming organisms (Khadre et al. 2001; Pascual et al. 2007). Microbial inactivation is carried out by means of molecular ozone and free radicals; as a result, cell membranes and wall components are attacked and destroyed. For this reason (cellular lysis), episodes of microbial resistance are not predictable (Pascual et al. 2007).

Ozone may be very useful from the environmental viewpoint; moreover, its application as a gas or in ozonated waters does not release undesired residuals (Cullen and Norton 2012; Pascual et al. 2007). In addition, the possible use of ozone-based CIP systems has been recently discussed (Canut and Pascual 2007).

Finally, other sanitisers are reported in the scientific literature with reference to single or synergic uses with 'main' sanitisers. For example, isopropanol may be used with quaternary ammonium salts. Another possible sanitising agent may be peracetic acid (Lundén et al. 2002).

References

Anonymous (2002) Cleaning and disinfecting in the food processing industry. Melrose Chemical Ltd. http://www.melrosechem.com/english/publicat/general/cleaning.pdf. Accessed 07 Jan 2015

Arrington ST (1991) Composition and method for removing iron containing deposits from equipment constructed of dissimilar metals. US Patent 5,015,298, 14 May 1991

Ball CO (1938) Advancement in sterilization methods for canned foods. J Food Sci 3(1–2):13–55. doi:10.1111/j.1365-2621.1938.tb17035.x

Bintsis T, Litopoulou-Tzanetaki E, Robinson RK (2000) Existing and potential applications of ultraviolet light in the food industry–a critical review. J Sci Food Agric 80(6):637–645. doi:10.1002/(SICI)1097-0010(20000501)80:6<637:AID-JSFA603>3.0.CO;2-1

Block SS (2001) Definition of terms. In: Block SS (ed) Disinfection, sterilization, and preservation. Lippincott Williams & Wilkins, Philadelphia, pp 19–28

Boxler C, Augustin W, Scholl S (2014) Composition of milk fouling deposits in a plate heat exchanger under pulsed flow conditions. J Food Eng 121:1–8. doi:10.1016/j.jfoodeng.2013.08.003

Canut A, Pascual A (2007) OzoneCip: ozone cleaning in place in food industries. In: IOA Conference and Exhibition 6(6):1–18, Valencia, Spain, Oct 2007

Casani S, Rouhany M, Knøchel S (2005) A discussion paper on challenges and limitations to water reuse and hygiene in the food industry. Water Res 39(6):1134–1146. doi:10.1016/j.watres.2004.12.015

Castillo A, Lucia LM, Goodson KJ, Savell JW, Acuff GR (1999) Decontamination of beef carcass surface tissue by steam vacuuming alone and combined with hot water and lactic acid sprays. J Food Prot 62(2):146–151

Chmielewski RAN, Frank JF (2003) Biofilm formation and control in food processing facilities. Compr Rev Food Sci Food Saf 2(1):22–32. doi:10.1111/j.1541-4337.2003.tb00012.x

Codex Alimentarius Commission (2003) Food hygiene basic texts, 3rd edn. Food and Agriculture Organization, Rome, and World Health Organization, Geneva

Cords BR, Dychdala GR (2003) Sanitizers: halogens, surfaceactive agents and peroxides. In: Davidson PM, Branen AL (eds) Antimicrobials in foods, 2nd edn. Marcel Dekker Inc, New York, pp 469–537

Cullen PJ, Norton T (2012) Ozone sanitisation in the food industry. In: Ozone in food processing. O'Donnell C, Tiwari BK, Cullen PJ, Rice RG (eds). Wiley, Chichester

Dempsey DJ, Thirucote RR (1988) Sterilization of medical devices: a review. J Biomater Appl 3(3):454–523. doi:10.1177/088532828800300303

Dickson JS, Cutter CG, Siragusa GR (1994) Antimicrobial effects of trisodium phosphate against bacteria attached to beef tissue. J Food Prot 57(11):952–955

Du Plessis A (2012) Surface active ingredient composition. US Patent 20,120,174,641, 12 July 2012

Evans JA, Russell SL, James C, Corry JE (2004) Microbial contamination of food refrigeration equipment. J Food Eng 62(3):225–232. doi:10.1016/S0260-8774(03)00235-8

Flint SH, Bremer PJ, Brooks JD (1997) Biofilms in dairy manufacturing plant-description, current concerns and methods of control. Biofouling 11(1):81–97. doi:10.1080/08927019709378321

Gil MI, Selma MV, López-Gálvez F, Allende A (2009) Fresh-cut product sanitation and wash water disinfection: problems and solutions. Int J Food Microbiol 134(1):37–45. doi:10.1016/j.ijfoodmicro.2009.05.021

Gilmore BH (1935) A new principle and agent in detergent operations. J Am Oil Chem Soc 12(2):29–32. doi:10.1007/BF02636639

Gorman BM, Sofos JN, Morgan JB, Schmidt GR, Smith GC (1995) Evaluation of hand-trimming, various sanitizing agents, and hot water spray-washing as decontamination interventions for beef brisket adipose tissue. J Food Prot 58(8):899–907

Hamid A, Bibi Z, Ghafoor I, Anwar Z, Khattak JZK (2013) Approach of bioremediation in olive oil and dairy industry: a review. Res J Appl Sci Eng Technol 5(6):2255–2263

Hennessy DA, Roosen J, Jensen HH (2003) Systemic failure in the provision of safe food. Food Policy 28(1):77–96. doi:10.1016/S0306-9192(03)00003-4

Hubig SM, Finley MJ, Hei RDP (2004) Recreational water treatment employing singlet oxygen. US Patent 20,040,055,965, 25 Mar 2004

Khadre MA, Yousef AE, Kim JG (2001) Microbiologicalaspects of ozone applications in food: a review. J Food Sci 66(9):1242–1252. doi:10.1111/j.1365-2621.2001.tb15196.x

Kirby RM, Bartram J, Carr R (2003) Water in food production and processing: quantity and quality concerns. Food Control 14(5):283–299. doi:10.1016/S0956-7135(02)00090-7

Juven BJ, Pierson MD (1996) Antibacterial effects of hydrogen peroxide and methods for its detection and quantitation. J Food Prot 59(11):1233–1241

Lawley R, Curtis L, Davis J (2012) The food safety hazard guidebook, 2nd edn. Royal Society of Chemistry, Cambridge

Leeder JG (1956) Milkstone -it can be controlled. J Dairy Sci 39(2):229–231. doi:10.3168/jds.S0022-0302(56)94735-X

Lindsay D, Von Holy A (1999) Different responses of planktonic and attached Bacillus subtilis and Pseudomonas fluorescens to sanitizer treatment. J Food Prot 62(4):368–379

Lindsay D, Brözel VS, Mostert JF, Von Holy A (2002) Differential efficacy of a chlorine dioxide-containing sanitizer against single species and binary biofilms of a dairy-associated Bacillus cereus and a Pseudomonas fluorescens isolate. J Appl Microbiol 92(2):352–361. doi:10.1046/j.1365-2672.2002.01538.x

Lundén JM, Autio TJ, Korkeala HJ (2002) Transfer of persistent Listeria monocytogenes contamination between food-processing plants associated with a dicing machine. J Food Prot 65(7):1129–1133

McGlynn W (2013) Guidelines for the use of chlorine bleach as a sanitizer in food processing operations. Oklahoma State University Food Technology Fact Sheet, FAPC-116. Reviewed February 2013. http://pods.dasnr.okstate.edu/docushare/dsweb/Get/Document-963/FAPC-116web.pdf. Accessed 19 Jan 2015

Parish ME, Beuchat LR, Suslow TV, Harris LJ, Garrett EH, Farber JN, Busta FF (2003) Methods to reduce/eliminate pathogens from fresh and fresh-cut produce. Compr Rev Food Sci Food Saf 2(s1):161–173. doi:10.1111/j.1541-4337.2003.tb00033.x

Parisi S (2002) Confronto tra diversi metodi di screening igienico delle superfici negli stabilimenti alimentari. Prod Bene Ig 188:3366

Parisi S (2006) Profili chimici delle caseine presamiche alimentari. Ind Aliment 457:377–383

Pascual A, Llorca I, Canut A (2007) Use of ozone in food industries for reducing the environmental impact of cleaning and disinfection activities. Trends Food Sci Technol 18(1):S29–S35. doi:10.1016/j.tifs.2006.10.006

Porter S (1972) Method of removing beer stone milk stone and railway carriage encrustations using a diphosphonic acid. US Patent 3,634,257, 11 Jan 1972

Richter FL, Cords BR (2001) Formulation of sanitizers and disinfectants. In: Block SS (ed) Disinfection, sterilization, and preservation. Lippincott Williams & Wilkins, Philadelphia, pp 473–487

Ropkins K, Beck AJ (2000) Evaluation of worldwide approaches to the use of HACCP to control food safety. Trends Food Sci Technol 11(1):10–21. doi:10.1016/S0924-2244(00)00036-4

Roselle BJ, Ward TE, Rollins DK (2004) US Patent 6,808,729, 26 Oct 2004

Rossoni EM, Gaylarde CC (2000) Comparison of sodium hypochlorite and peracetic acid as sanitising agents for stainless steel food processing surfaces using epifluorescence microscopy. Int J Food Microbiol 61(1):81–85. doi:10.1016/S0168-1605(00)00369-X

Rovison JM, Lapham III D, Abraham S, Homan M (2007) Peracetic Acid Composition. US Patent 20,090,312,292, 17 Dec 2009

Schmidt RH (1997) Basic elements of equipment cleaning and sanitizing in food processing and handling operations. Fact Sheet FS-14, University of Florida, Institute of Food and Agriculture Sciences, Cooperative Extension Service. http://www.us.rexroth.com/country_units/america/

united_states/sub_websites/brus_packaging_processing/en/a_downloads/UF_equipmentcleaning.pdf. Accessed 17 Jan 2015

Schmidt RH, Erickson DJ (2008) Sanitary design and construction of food processing and handling facilities. FSHN0408, University of Florida, Food Science and Human Nutrition Department, UF/IFAS Extension. http://edis.ifas.ufl.edu/pdffiles/FS/FS12000.pdf. Accessed 19 Jan 2015

Scott E, Bloomfield SF (1990) The survival and transfer of microbial contamination via cloths, hands and utensils. J Appl Bacteriol 68(3):271–278. doi:10.1111/j.1365-2672.1990.tb02574.x

Sivapalasingam S, Friedman CR, Cohen L, Tauxe RV (2004) Fresh produce: a growing cause of outbreaks of foodborne illness in the United States, 1973 through 1997. J Food Prot 67 (10):2342–2353

Slifko TR, Smith HV, Rose JB (2000) Emerging parasite zoonoses associated with water and food. Int J Parasitol 30(12):1379–1393. doi:10.1016/S0020-7519(00)00128-4

Stanfield P (2003) Sanitation of food processing equipment. In: Hui YH, Bruinsma LB, Gorham J, Nip WK, Tong PS, Ventresca P (eds) Food plant sanitation. Marcel Dekker, New York, p 191

Stanga M (2010) Sanitation: cleaning and disinfection in the food industry. Wiley-VCH Verlag GmbH & Co., KGaA, Weinheim

Wang H, Feng H, Luo Y (2004) Microbial reduction and storage quality of fresh-cut cilantro washed with acidic electrolyzed water and aqueous ozone. Food Res Int 37(10):949–956. http://dx.doi.org/10.1016/j.foodres.2004.06.004

WHO (1996) Guidelines for drinking-water quality, 2nd edn., Volume 2 – health criteria and other supporting information. World Health Organization (WHO), Geneva. http://www.who.int/water_sanitation_health/dwq/2edvol2p1.pdf. Accessed 19 Jan 2015

Xavier, G. (1999). Asepsis. Nurs Stand 13(36):49–53. doi:10.7748/ns1999.05.13.36.49.c2610

Chapter 7
Reasons for the Substitution of Chlorine in the Disinfection

Abstract In general, the disinfection of food-contact surfaces in food industries is carried out by means of a two-step process (cleaning and sanitisation). With relation to sanitising agents, the choice should consider the following agents: inorganic and organic, chlorine products, organic chlorine products, iodine and iodophores, acid-anionic and fatty acid sanitisers, ozone, peroxides, quaternary ammonium salts and synthetic phenols. All these chemical sanitisers have their own advantages and risks. At present, none of the above-mentioned substances can be defined the best sanitising agent. However, the use of chlorine-based chemical is well known and currently demonstrated because of different factors. However, the use of chlorine in food industries is highly concerned because of different problems, including also the known irritating attitude to skin and mucosae membranes. This chapter is dedicated to safety and toxicological concerns caused by the introduction of chlorine-based chemicals in food industries.

Keywords Carcinogenicity · Chlorine dioxide · Cleaning · Corrosion · Irritating effect · Sanitisation

7.1 Sanitisation in Food Industries: The Role of Chlorine-Based Compounds

The limitation or the eradication of microbial risks into food industries and correlated plants may be obtained by means of different procedures (Evans et al. 2004; Ropkins and Beck 2000; Scott and Bloomfield 1990), including the creation and the implementation of correct cleaning and sanitising systems (Sect. 6.1).

Normally, the sanitisation of process waters and food-contact surfaces in food plants is carried out by means of the use of different chemicals as cleaners and sanitisers (Sect. 6.2). With exclusive relation to the final step (sanitisation, often confused with 'disinfection' (Sect. 6.1), food business operators can reasonably use only a few selected methods. In general, disinfection can be carried out with the following methods at least (Bintsis et al. 2000; Casani et al. 2005):

G. Gurnari, *Safety Protocols in the Food Industry and Emerging Concerns*,
Chemistry of Foods, DOI 10.1007/978-3-319-16492-2_7

- Caustic substances
- Heating processes
- Oxidising chemicals
- Ultraviolet light.

On the other hand, the use of innovative systems—electrolysed water, ozonated water, ozone as gas, synergic ozonisation and ultraviolet light treatment, etc.—may be tried. In these situations, the final decision depends on different factors, including the simple economic ‘weight’ of the involved technology in comparison with final results in terms of destruction of vegetative cells (Block 2001; Codex Alimentarius Commission 2003; Schmidt 1997).

The disinfection of food-contact surfaces cannot be carried out with good results without the preliminary cleaning, in accordance with a basic sequence such as the below-mentioned protocol (Stanfield 2003):

(1) Manual removal of loose materials
(2) Chemical cleaning
(3) Final rinsing with cold or hot water
(4) Timing of maintenance program.

The final step of cleaning and sanitising operations in food plants corresponds to the true ‘sanitisation’ (Sect. 6.2). This operation should be considered ‘mandatory’ because of the necessity of eliminating or inactivating pathogen microorganisms (and reducing spoilage microorganisms) without subsequent treatments.

Generally, the most part of sanitising treatments in the food industry concerns the use of chemical sanitisers. Before going on, it should be highlighted that these substances cannot (Schmidt 1997; Schmidt and Erickson 2008; Stanfield 2003):

(a) Destroy, corrode, stain or leave undesired films on treated surfaces
(b) Be toxic for human consumption
(c) Be dangerous for use (into food plants).

In addition, these sanitisers should be produced and/or formulated with the aim of realising aqueous mixtures that can destroy, inactivate or reduce the most part of microorganisms rapidly (Lawley et al. 2012; Richter and Cords 2001; Rossoni and Gaylarde 2000). Unfortunately, currently available solutions may be the best sanitiser in certain applications and food production environments, while other problems may require very different chemicals or systems. In detail, the so-called ‘sanitising performance’ may be reduced depending on peculiar conditions, including the presence of superficial damages, pH and/or temperature values for the aqueous solution, etc. (Sect. 6.2).

For these reasons, the choice appears quite limited at present. From a general viewpoint, it can be assumed that the current solution in food industries is researched in the following list (Schmidt 1997; Stanfield 2003):

(a) Inorganic chlorine products (liquid chlorine, sodium hypochlorite, inorganic chloramines, etc.)
(b) Organic chlorine products

(c) Other chlorine compounds: chlorine dioxide
(d) Iodine and iodophores
(e) Acid-anionic sanitisers
(f) Fatty acid sanitisers
(g) Quaternary ammonium salts
(h) Peroxides
(i) Synthetic phenols
(j) Ozone.

All these chemical sanitisers have their own advantages and risks. At present, none of the above-mentioned substances can be defined ‘the best sanitising agent’. However, the use of chlorine-based chemical is well known and currently demonstrated because of different factors (Anonymous 2002).

On the other hand, the use of chlorine in food industries is highly concerned (Sect. 6.2.1.1) because of different problems, including also the known irritating attitude to skin and mucosae membranes (Anonymous 2002; Gil et al. 2009). As a result, the use of different sanitisers such as chlorine dioxide (ClO_2) has been recommended (Sect. 6.1). This chapter is dedicated to safety and toxicological concerns caused by the introduction of chlorine-based chemicals in food industries. Interestingly, some of these risks are typically linked to chlorine-based compounds. In other terms, other sanitisers are generally perceived as ‘low-risk’ substances if compared with sodium hypochlorite and other chlorine-releasing agents.

7.2 Chlorine-Based Chemicals: Safety and Toxicological Concerns

Inorganic chlorine products (liquid chlorine, sodium hypochlorite, chloramines, etc.) and organic compounds release hypochlorous acid and hypochlorite, when dissolved in water (McGlynn 2013).

In general, the most important safety and toxicological concerns are listed as follows:

(1) Undesirable off-odours
(2) Corrosion power
(3) Irritating effects (skin, respiratory organs)
(4) Production of carcinogenic substances
(5) Explosion risks.

7.2.1 *Odour Failures*

First of all, chlorine is well known in the food industry because of the peculiar and unpleasant odour (Schmidt 1997). In particular, it has been reported that certain products in brine or syrup (starch solutions have been also cited) may show the distinctive chlorine odour because of the use of sanitised chlorinated water (Reineccius 1991; Schmidt 1997). The problem is generally dependent on the quantitative absorption of chlorine by syrup or starch solutions. At present, one of the main solutions appears the heating of chlorinated waters before the production of brine, syrup or starch solutions. The same defect has been also reported with relation to iodine in brine solutions.

7.2.2 Corrosion Power

Chlorine is a natural strong oxidising agent. This property can explain very well the known corrosion power of such a molecule on metal surfaces (Nishimura et al. 2000; Novak et al. 2001; Refait et al. 1998). As a result, the production of rust—and the appearance of small or large areas with superficial damages, cracks, micro fractures and possible biofilm formation may be partially avoided with the use of other sanitisers such as quaternary ammonium salts (Schmidt 1997). It should be also considered that the lower the pH value of the final sanitising solution, the higher the corrosion power. In other words, should be pH lower than 6.0, the final solution would be very corrosive (Schmidt 1997).

7.2.3 Irritating Effects on Skin and Respiratory Organs

Chlorine can irritate the skin when dissolved in water. Moreover, the evolution of gaseous chlorine can invade and damage respiratory organs (Bernard 2007; Evans 2005). In detail, the following adverse effects have been reported at present as the consequence of chemical burning (Williams 2010):

- Immediate vomiting
- Immediate intolerance/anaphylactic shock
- Short- to long-term illness.

For these reasons, operators have to be adequately protected by means of protective clothing. In addition, cleaning and sanitising procedures should be always carried out under an adequate forced ventilation system (Schmidt 1997).

Another remarkable concern is linked to the pH of the final solution. In fact, the production of chlorine gas is normally enhanced if pH is lower than 5.0 (Schmidt 1997). The equilibrium between hypochlorous acid and chlorine favours the production of gaseous chlorine (deadly chlorine, mustard gas) when protons are abundant in solution. For this reason, the addition of acid substances to chlorine solution is dangerous.

7.2.4 Production of Carcinogenic Substances

Recently, the detection of peculiar carcinogenic substances such as trihalomethanes, haloketones or chloropicrin has been correlated to the presence of chlorine in certain conditions (Bull et al. 1995; Condie 1986; Dunnick and Melnick 1993; Gil et al. 2009). However, the matter is still debated.

7.2.5 Explosion Risks

Finally, the possible explosion of ClO_2 in highly concentrated solutions should be considered when speaking of chlorine dioxide as a valid substitution for normal chlorine-based compounds. This gas can easily react under light or when environmental temperatures are ≥50 °C (Schmidt 1997).

References

Anonymous (2002) Cleaning and disinfecting in the food processing industry. Melrose Chemical Ltd. http://www.melrosechem.com/english/publicat/general/cleaning.pdf. Accessed 07 Jan 2015

Bernard A (2007) Chlorination products: emerging links with allergic diseases. Curr Med Chem 14 (16):1771–1782. doi:10.2174/092986707781058940

Bintsis T, Litopoulou-Tzanetaki E, Robinson RK (2000) Existing and potential applications of ultraviolet light in the food industry–a critical review. J Sci Food Agric 80(6):637–645. doi:10.1002/(SICI)1097-0010(20000501)80:6<637:AID-JSFA603>3.0.CO;2-1

Block SS (2001) Definition of terms. In: Block SS (ed) Disinfection, sterilization, and preservation. Lippincott Williams & Wilkins, Philadelphia, pp 19–28

Bull RJ, Birnbaum L, Cantor KP, Rose JB, Butterworth BE, Pegram REX, Tuomisto J (1995) Water chlorination: essential process or cancer hazard? Toxicol Sci 28(2):155–166. doi:10.1093/toxsci/28.2.155

Casani S, Rouhany M, Knøchel S (2005) A discussion paper on challenges and limitations to water reuse and hygiene in the food industry. Water Res 39(6):1134–1146. doi:10.1016/j.watres.2004.12.015

Codex Alimentarius Commission (2003) Food hygiene basic texts, third edition. Food and Agriculture Organization, Rome, World Health Organization, Geneva

Condie LW (1986) Toxicological problems associated with chlorine dioxide. J Am Water Works Assoc 78(6):73–78

Dunnick JK, Melnick RL (1993) Assessment of the carcinogenic potential of chlorinated water: experimental studies of chlorine, chloramine, and trihalomethanes. J Natl Cancer Inst 85 (10):817–822. doi:10.1093/jnci/85.10.817

Evans RB (2005) Chlorine: state of the art. Lung 183(3):151–167. doi:10.1007/s00408-004-2530-3

Evans JA, Russell SL, James C, Corry JE (2004) Microbial contamination of food refrigeration equipment. J Food Eng 62(3):225–232. doi:10.1016/S0260-8774(03)00235-8

Gil MI, Selma MV, López-Gálvez F, Allende A (2009) Fresh-cut product sanitation and wash water disinfection: problems and solutions. Int J Food Microbiol 134(1):37–45. doi:10.1016/j.ijfoodmicro.2009.05.021

Lawley R, Curtis L, Davis J (2012) The food safety hazard guidebook, 2nd edn. Royal Society of Chemistry, Cambridge

McGlynn W (2013) Guidelines for the use of chlorine bleach as a sanitizer in food processing operations. Oklahoma State University Food Technology Fact Sheet, FAPC-116. Reviewed February 2013. http://pods.dasnr.okstate.edu/docushare/dsweb/Get/Document-963/FAPC-116web.pdf. Accessed 19 Jan 2015

Nishimura T, Katayama H, Noda K, Kodama T (2000) Electrochemical behavior of rust formed on carbon steel in a wet/dry environment containing chloride ions. Corrosion 56(9):935–941. doi:10.5006/1.3280597

Novak P, Mala R, Joska L (2001) Influence of pre-rusting on steel corrosion in concrete. Cement Concr Res 31(4):589–593. doi:10.1016/S0008-8846(01)00459-8

Refait P, Abdelmoula M, Génin JM (1998) Mechanisms of formation and structure of green rust one in aqueous corrosion of iron in the presence of chloride ions. Corr Sci 40(9):1547–1560. doi:10.1016/S0010-938X(98)00066-3

Reineccius G (1991) Off-flavors in foods. Crit Rev Food Sci Nutr 29(6):381–402. doi:10.1080/10408399109527534

Richter FL, Cords BR (2001) Formulation of sanitizers and disinfectants. In: Block SS (ed) Disinfection, sterilization, and preservation. Lippincott Williams & Wilkins, Philadelphia, pp 473–487

Ropkins K, Beck AJ (2000) Evaluation of worldwide approaches to the use of HACCP to control food safety. Trends Food Sci Technol 11(1):10–21. doi:10.1016/S0924-2244(00)00036-4

Rossoni EM, Gaylarde CC (2000) Comparison of sodium hypochlorite and peracetic acid as sanitising agents for stainless steel food processing surfaces using epifluorescence microscopy. Int J Food Microbiol 61(1):81–85. doi:10.1016/S0168-1605(00)00369-X

Schmidt RH (1997) Basic elements of equipment cleaning and sanitizing in food processing and handling operations. Fact Sheet FS-14, University of Florida, Institute of Food and Agriculture Sciences, Cooperative Extension Service. http://www.us.rexroth.com/country_units/america/united_states/sub_websites/brus_packaging_processing/en/a_downloads/UF_equipmentcleaning.pdf. Accessed 17 Jan 2015

Schmidt RH, Erickson DJ (2008) Sanitary design and construction of food processing and handling facilities. FSHN0408, University of Florida, Food Science and Human Nutrition Department, UF/IFAS Extension. http://edis.ifas.ufl.edu/pdffiles/FS/FS12000.pdf. Accessed 19 Jan 2015

Scott E, Bloomfield SF (1990) The survival and transfer of microbial contamination via cloths, hands and utensils. J Appl Bacteriol 68(3):271–278. doi:10.1111/j.1365-2672.1990.tb02574.x

Stanfield P (2003) Sanitation of food processing equipment. In: Hui YH, Bruinsma LB, Gorham J, Nip WK, Tong PS, Ventresca P (eds) Food plant sanitation. Marcel Dekker, New York, p 191

Williams A (2010) HACCP systems for ensuring the food safety of canned fish products. In: Bratt L (ed) Fish canning handbook, Wiley, Oxford. doi:10.1002/9781444323405