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Minimally Processed Foods

Technologies for Safety, Quality, and Convenience

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Preface

Preservation of food is crucial to achieve global food supply and its safety with desired sensory and nutritional quality. The traditional as well as advance methods are being used to achieve the desired shelf life with appropriate nutrients, appealing color, flavor, and texture. In principle, all foods are not subjected to the same degree or severity of processing. The minimally processed foods are constantly growing due to their increased demand by the consumers. There are different types of products under mimimally processed foods, for example, fresh-cut, ready-to-serve, ready-to-eat, and/or ready-to-cook, cook-chill, cook-freeze, part-baked products. Always there is an attempt to use low severity of processing as well as minimal chemicals. The foods termed as *minimally processed* are fresh like products that need special care in preparation, processing, storage, and handling. The minimal processing techniques maintain the desired shelf life and safety of the products with higher sensory and nutritional quality. The new or novel technologies are being applied to achieve high quality safe minimally processed foods. The scientists are continuously working to develop new technologies to fulfil the consumers' expectations. In terms of science and applications, several advances on new technologies have been achieved to develop new minimally processed foods with desired safety, quality, and convenience.

The safety and efficacy of minimal processing depend on the use of novel preservation technologies. A professional food manufacturer, food scientist, food engineer, and/or postharvest technologist indulged in the processing of minimally processed foods should be well versed with the basic principles, processes, as well as quality and safety concerns. This book "**Minimally Processed Foods: Technologies for Safety, Quality, and Convenience**" has been developed primarily for fulfilling these expectations and intended to be used by the students in the undergraduate and graduate courses in Food Process Engineering/Food Technology/ Postharvest Technology. This would be a valuable source to the professionals working in the food industry. It could also be used by graduates of other disciplines, such as Horticulture and/or Livestock Products Technology.

Editors of this book have an adequate experience in teaching, research, and extension activities related to food science and postharvest technology. They have realized a need of such reference book that covers many important aspects of plant- and animal-based minimally processed foods, starting from farm to fork. They endeavored to gather eminent academics and professionals across the globe for their contributions in this book. The authors have diverse backgrounds and vast experiences in the field. Each chapter of this book is intended to provide concise, to-the-point descriptions of basic principles, technologies, and applications in different categories of minimally processed foods.

The book contains 12 chapters and the first chapter determines/describes the scope of the minimally processed foods and available new technologies or methods to produce quality products in terms of safety and nutrition. Chapter 2 presents hurdle concepts in food preservation and processing. It explains the individual assessment of each product using logical tree based on their hurdles as proposed by IFT/FDA. Theoretical concepts of F-value, water activity, glass transition, state diagram, and macro–micro region concepts are explained in order to apply these in determining food stability. A brief overview on the prediction models is also presented. Chapter 3 has devoted to basic principles and methods of packaging required for minimally processed foods. Chapters 4 and 5 are well versed with important operations (i.e., washing, peeling, cutting) and technologies (traditional and novel) involved in manufacturing of plant-based fresh-cut products. The new technologies or methods, such as edible coating, natural preservatives (i.e., antimicrobial, flavour enhancer, anti-browning), advanced packaging (active, antimicrobial, and modified or controlled atmosphere), and selected nonthermal techniques (high pressure, pulsed electric field, ultrasound, light) are also included. Chapter 6 concisely describes the trends, convenience, and safety issues of ready meals. Cook-chill and half-baked/part-baked products have been an important category of minimally processed foods. These are most popular ones owing to their benefits in terms of quality, safety, and convenience. Three chapters 7–9 are dedicated to processing, quality, and storage issues of these products. Nowadays, the production and processing of meat and fish products without compromising safety and quality is a challenge. The chapters 10 and 11 deal with various conventional and latest minimal processing approaches used in meat and seafood products. Finally, the chapter 12 discusses the important issues of minimal processing in terms of the sustainability and challenges along with remedial measures to preserve the quality and safety of minimally processed foods.

The editors are confident that this book will prove to be a standard reference work for the food industry in developing minimally processed foods. The information can be used to extend the shelf life by retaining safety as well as nutritional and sensory quality. The editors would appreciate receiving new information and comments to assist in the future development of the next edition.

Sabour, Bhagalpur, India — Mohammed Wasim Siddiqui
Al-khod, Oman — Mohammad Shafiur Rahman

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Some rare, auspicious moments come in life when words are totally insufficient to express the heartfelt emotion. It was almost impossible to reveal the deepest sense of veneration to all without whose precious exhortation, this book project could not be completed. At the onset of the acknowledgment, we ascribe all glory to the Gracious "Almighty Allah" from whom all blessings come. We would like to thank for His blessings to write this book.

With a profound and unfading sense of gratitude, we wish to express our sincere thanks to the Bihar Agricultural University, India, and Sultan Qaboos University, Sultanate of Oman, for providing us the opportunity and facilities to execute such an exciting project, and supporting us towards our research and other intellectual activities around the globe. We convey special thanks to our colleagues and other research team members for their support and encouragement for helping us in every footstep to accomplish this venture. We would like to appreciate Ms. Susan Safren, Ms. Anne Meagher, and Mr. Daniel Falatko of Springer Publisher for their continuous support to complete the project.

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About the Editors

Mohammed Wasim Siddiqui Dr. Md. Wasim Siddiqui is an Assistant Professor and Scientist in the Department of Food Science and Technology, Bihar Agricultural University, Sabour, India, and author or coauthor of 24 peer reviewed journal articles, 13 book chapters, and 16 conference papers. He has three books to his credit published by CRC Press & Apple Academic Press, USA. Recently, Dr. Siddiqui has established an international peer reviewed journal "Journal of Postharvest Technology." Dr. Siddiqui is an *Acquisitions Editor* in Apple Academic Press, New Jersey, USA for Horticultural Science. He has been honored to be the *Editor-in-Chief* of a book series entitled "*Postharvest Biology and Technology*" being published from Apple Academic Press, New Jersey, USA. He has been serving as an editorial board member of several journals.

Dr. Siddiqui acquired B.Sc. (Agriculture) degree from Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur, India. He received the M.Sc. (Horticulture) and Ph.D. (Horticulture) degrees from Bidhan Chandra Krishi Viswavidyalaya, Mohanpur, Nadia, India, with specialization in the Postharvest Technology. He was awarded Maulana Azad National Fellowship Award from the University Grants Commission, New-Delhi, India. He is a member of "Core Research Group" at the Bihar Agricultural University (BAU) and providing appropriate direction and assisting to sensitize priority of the research. He has received several grants from various funding agencies to carry out his research projects. Dr. Siddiqui has been associated to postharvest technology and processing aspects of horticultural crops. He is dynamically indulged in teaching (graduate and doctorate students) and research, and he has proved himself as an active scientist in the area of Postharvest Technology.

Mohammad Shafiur Rahman Mohammad Shafiur Rahman, Professor at the Sultan Qaboos University, Sultanate of Oman, and the author or co-author of over 300 technical articles including 117 refereed journal papers, 107 conference papers, 66 book chapters, 34 reports, 13 popular articles, and 8 books. He is the author of the internationally acclaimed and award-wining Food Properties Handbook, published by CRC Press, Boca Raton, FL, which was one of the bestsellers from CRC Press in 2002. The second edition is now released with his editorship. The editor of

the popular book Handbook of Food Preservation published by CRC Press, Boca Raton, FL. The first edition received one of the bestsellers from CRC press in 2003, and the second edition is now in the market. The first edition was translated into Spanish. He is one of the editors of Handbook of Food Process Design (two volumes) published by Wiley-Blackwell, Oxford, England in 2012. He was invited to serve as one of the associate editors for the Handbook of Food Science, Engineering and Technology, and one of the editors for the Handbook of Food and Bioprocess Modeling Techniques published by CRC Press, FL.

Professor Rahman has initiated the International Journal of Food Properties (Marcel Dekker, Inc.) and serving as the founding editor for more than 15 years. In addition he is serving in the editorial boards of eight international journals. He is a member in the Food Engineering Series Editorial Board of Springer Science, New York. He is serving as a Section Editor for the Sultan Qaboos University journal Agricultural Sciences. In 1998 he has been invited and continued to serve as a Food Science Adviser for the International Foundation for Science (IFS) in Sweden.

Professor Rahman is a professional member of the New Zealand Institute of Food Science and Technology and the Institute of Food Technologists, and Member of Executive Committee for International Society of Food Engineering, ISFE. He was involved in many professional activities, such as organizing international conferences, training workshops, and other extension activities. He has initiated and served as the Founding Chair of the International Conference on Food Properties (iCFP). He was invited as a key note/plenary speaker in eight international conferences. He received the B.Sc. Eng. (Chemical) (1983) and M.Sc. Eng. (Chemical) (1984) degrees from Bangladesh University of Engineering and Technology, Dhaka, the M.Sc. degree (1985) in food engineering from Leeds University, England, and the Ph.D. degree (1992) in food engineering from the University of New South Wales, Sydney, Australia.

Professor Rahman has received numerous awards and fellowships in recognition of research/teaching achievements, including the HortResearch Chairman's Award, the Bilateral Research Activities Program (BRAP) Award, CAMS Outstanding Researcher Award 2003, SQU Distinction in Research Award 2008, and the British Council Fellowship. In 2008 Professor Rahman was ranked among the top five Leading Scientists and Engineers of 57 OIC Member States in the Agroscience Discipline.

Professor Rahman is an eminent scientist and academic in the area of Food Processing. He is recognized for his significant contribution to the basic and applied knowledge of food properties related to food structure, food functionality, engineering properties, and food stability. His total SCOPUS and Google Scholar citations are 1,851 and 3,566, respectively, which indicates the high impact of his research in the international scientific community.

Chapter 1
Minimally Processed Foods: Overview

Vasudha Bansal, Mohammed Wasim Siddiqui, and Mohammad Shafiur Rahman

1.1 Introduction

Over the past decades, consumers want fresh like foods with their natural nutritive values and sensory attributes, such as flavor, odor, texture and taste (Huxley et al. 2004). Fresh fruits and vegetables are the good examples of convenient foods. This growing consumers' demand of minimally processed foods with no or lesser synthetic additives pose challenges to food technologists (Siddiqui et al. 2011). In addition, demand of functional foods to prevent or control of diseases are growing (Monteiro et al. 2011). All these demands force to develop safe foods with minimal processing techniques (Gilbert 2000). This is not a simple task to produce safe minimally processed foods with desired shelf-life.

Minimally processed foods can be kept safe with partial or minimal preservation treatment. In addition, it results fewer possible alterations to the food quality (Ohlsson 1996). Therefore, the fresh cut fruit and vegetable industry is working continuously on diversity of minimally processed products to meet the needs of the consumers (Ragaert et al. 2004). The minimal processing caused minimal influence on the quality attributes during their storage or shelf life (Allende et al. 2006; HuisIn't Veld 1996; Marechal et al. 1999). In food processing the term mild technologies is

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also used to express the technique which allows minimal physicochemical, oxidative and mechanical damage to the food products. The aims of minimal processing are as follows: (i) to make the food safe chemically and microbiologically, (ii) to retain the desired flavor, color and texture of the food products, and (iii) to provide convenience to the consumers.

1.2 Purposes of Minimal Processing

The purposes of minimal processing are included in the Table 1.1 (Dharmabandu et al. 2007; Monteiro et al. 2010; Ohlsson and Bengtsson 2002). Overall the purpose is to prepare ready meals easily and quickly. The advantages of minimally processing are (1) convenience in terms of easy and quick preparation of meals, (2) low severity of the processing methods (i.e. most of the cases it uses multi-hurdles or multi-preservation methods), (3) maintain quality as fresh or close to the fresh prepared meals or products, (4) maintain products' nutritive values, (5) provide varied shelf-life depending on the types and severity of preservation hurdles used.

1.3 Applications of Minimal Processing

1.3.1 Plant Based Minimally Processed Foods: Fresh Fruits and Vegetables

Minimal processing can be broadly divided into two categories: first one is based on plant source, such as fruits and vegetables, and another one animal based, such as meat, fish and sea foods. In addition, other categories (i.e. combinations of different sources) are also appearing in the market, such as part-bread, ready-meal, cook-chill, cook-freeze products. The fruits and vegetables are composed of fragile tissues,

Table 1.1 The purposes of minimally processed foods

Minimally processed foods
• Include all the operations (sorting, washing, peeling, slicing, etc.) that must be carried out before blanching in a conventional processing line
• Include value addition, such as chopping, husking, coring, low level irradiation, and individual packaging
• Maintain quality attributes similar to those of fresh products (i.e. fruits and vegetables) or similar to the products' characteristics when consumed (i.e. part-bread, cook-chill, cook-freeze, sous-vide, ready-meal)
• Include procedures that cause fewer possible changes in the foods' quality (keeping their freshness appearance), and provide enough shelflife to transport it from the production site to the consumer

which need to be handled with care in order to prevent damages during processing and the damages can result spoiled fruits and vegetables. It needs to protect from initial microbial contaminations. Therefore, it is important to use the guidelines to maintain its quality.

The shelf life of fruits and vegetables is largely depicted from the perseverance of sensory parameters. The fruits and vegetables are prone to microbial spoilage since these are composed of enzymes, pectin and near acidic pH, and high water activity (González-Aguilar et al. 2010). Therefore, harvesting, processing, packaging and storage should be carefully guarded in order to maintain the quality. More regulations and guidelines need to be clearly defined. Microbes as *Staphylococcus aureus*, *Clostridium perfringens*, *Escherichia coli*, *Campylobacter jejuni*, *Clostridium botulinum*, *Listeria monocytogenes*, *Salmonella* spp. are concerned for the major damages. Therefore, standard requirements should be followed for grading, sorting, washing, peeling, chopping and shredding. It is important to avoid harsh washing and to use disinfectants during washing. The quality of the products depend on these treatments. The major enzymes present in these perishable products are polyphenoloxidase, polygalacturonase, lipooxygenase. These play an essential role in initiating the oxidation process. They are also responsible for the spoilage in the cases of cut surfaces for diced or sliced fruits and vegetables. In the cases of products with pH higher than 6, there is more possible growth of microbes since cut surface is exposed to air and invites bacteria, yeasts and molds. Minimally processed fruits and vegetables are not allowed to have heat treatment abuse and they must store at 4–7 °C chilled storage. The followings are important to maintain:

- Careful selection of cultivars, appropriate pre- and post-harvest condition, and maintain chill storage conditions.
- Abiding HACCP guidelines.
- Maintenance of hygiene.
- Maintain low temperature in the processing area.
- Maintain washing with flow of water and mild acids.
- Tender cutting, peeling and shredding.
- Preventheat abuse for retarding browning and oxidation.
- Keep the pH 5 or less than 5 throughout the controlled processing.
- Adequate chilled conditions for storage and distribution.
- Use vacuum packaging.

1.3.2 Animal Based Minimal Processed Foods: Meat and Sea Foods

Recently, non-thermal processing, such as high hydrostatic pressure, pulsed electric fields (PEF), oscillating magnetic fields, use of irradiation, use of natural antimicrobials are being applied animal based food products (i.e. tender meat, fish, and sea foods). These treatments can keep the texture, flavor and taste alive without any

detrimental effects to their tender tissues. Sea foods are more prone to the attack of micro-organisms. Therefore, combination of minimal processing techniques can create wonder for inactivating the microbes on one side and maintain nutritive values.

The qualities of animal-based food rely on the desired flavor, taste, color, and odor by the consumers. The typical spoilage of seafood and meat occur by denaturation of their proteins, which further involve the dissociation of their structures, protein aggregation, and protein gelation (Cheftel 1995). Furthermore, denaturation depends on the internal and external factors. Examples of external factors are temperature, and internal factors are pH, and enzymes. The spores are difficult to kill using minimal processing of hydrostatic pressure. However, combination of heat and non-thermal techniques along refrigeration storage can result into the convincing strategy. High hydrostatic pressure has seemed to work well with surface property of fish and meat and preserved the texture and appearance to the acceptable limits.

1.4 Quality and Safety of Minimally Processed Foods

The types of minimally processed foods are given in Table 1.2. The first category of plant based products are: fruits and unsweetened fruit juices, vegetables as roots, tubers and beans (fresh, frozen, dried), legumes, grains, seeds, and nuts.

Table 1.2 Types of minimally processed foods

Plant based products				Animal based products	
Fruits	Vegetables	Legumes	Extracted foods	Milk	Poultry/ fleshy
Chilled	*Peeled and Slices*	Peas	Sweeteners	Pasteurized	Eggs
Peech	Potato	*Whole pulses*	Starches	*Fermented milk*	Dried meat
Mango	Carrot	Black gram	Oils	Curd	Frozen meat
Strawberry	*Shredded*		Nuts	Yoghurt	Fish
Sliced	Cabbage		Seeds	Probiotic drinks	
Mango	Lettuce		Grains	Cheese	
Pineapple	Spinach		Herbs infusion		
Apricot	*Diced*		Tea		
Orange	Onion		Coffee		
Guava	Broccoli florets				
Melon	Cauliflower				
	Roots				
	Tubers				
Frozen					
	Beans				
	Peas				

These products are subjected to varied processing steps. Second category includes: extracted form from plant source foods, such as starches, sugars, oils, and cereals, sweeteners, herbs, tea, coffee.

In the case of fresh cut minimally processed fruits and vegetables, elevated respiration and transpiration rates result water loss from the plant tissues. This decreases the firmness of treated products (Hui et al. 2006). The usage of chlorine in the processing can have the devastating effects. They tend to form carcinogenic derivatives in water, therefore, these encompasses the need of alternative disinfectant (Tripathi et al. 2011). The calcium used to extend the shelf life of fruits and vegetables reacts with pectins present in the cell walls of fruits and vegetables and form the salts like calcium pectate.

Animals based minimally processed foods are: fresh and pasteurized milk, fermented milk as yoghurt, cheese, probiotic drinks, dried and frozen meat, fish, poultry and fish. Several methods are currently available for the extension of shelf life in minimally processed foods (Table 1.3). Consistent interest in the mild preservation fosters the development of multidimensional preservation proposition.

Table 1.3 Methods available for shelf-life extension of minimally processed products

Method(s)	Example(s)	Target	Advantage(s)
Acidulants	Citric acid	Enzymatic browning	Cheap and available from natural sources
Antioxidant	Ascorbic acid	Enzymatic browning	Cheap
Preservatives	Sulphite	Enzymatic browning	Cheap and highly effective
Antiomicrobials	Hypochlorite	Microbial contamination	Cheap
Modified atmospheric packaging	Low oxygen atmosphere	Metabolic response, Enzymatic browning, Microbial colonization	Effective for prevention of deterioration resulting from several factors
UV-light	UV-C	Microbial contamination	Effective surface sterilization
Essential oils	–	Enzymatic browning, Microbial colonization	Highly effective, Natural products
Plant growth regulator	6-benzylaminopurine	Metabolic response, Enzymatic browning, Water loss	Effective for prevention of deterioration resulting from several factors

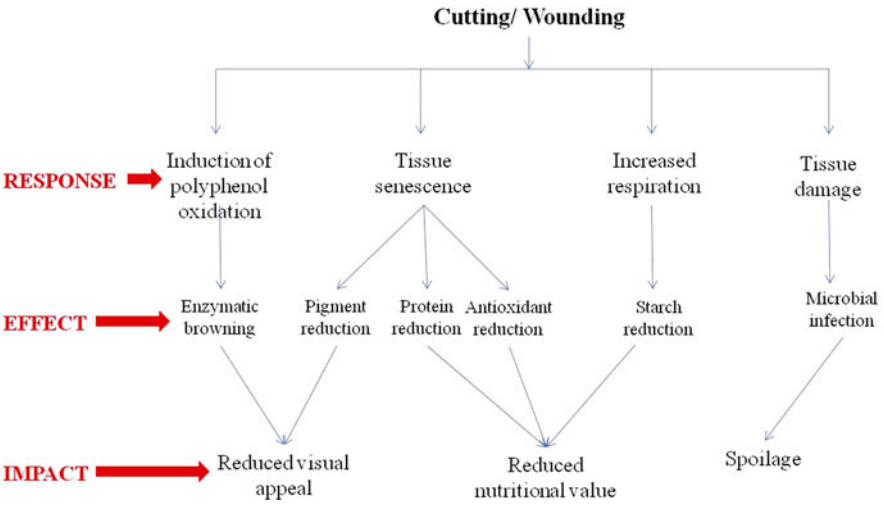

Fig. 1.1 Wounding or cutting consequences in minimally processed products

1.5 Impact of Minimal Processing on Quality of Food Products

The quality aspects of minimally processed products play an important role in marketing and securing consumer acceptance. Sensory appealing is one of the major factors for the freshness and organoleptic characteristics. These parameters include appearance, shape, color, flavor, textural quality as firmness, toughness, moistness and juiciness, and crispiness. Similarly the devoid of cut surfaces, avoid discoloration and fluid leaking from the tissues. The cutting or wounding of minimally processed products renders them vulnerable to microbial infection and enzymatic browning with higher metabolic activities (Fig. 1.1).

The above factors largely depend on the composition and nutritional components. The available phenolic compounds and colored pigments render antioxidant activity. Tissue sensitivity is also a delicate issue of the fresh fruits and vegetables as it can be the source of microbiological spoilage activity (Hodges and Toivonen 2008). Tissue softening is also resulted from the wounds and ripening of the plant based foods (Toivonen and Brummell 2008).

Sensory parameters, such as flavor, sweetness, sourness, acidity, astringency, bitterness largely depend on the post harvesting operations and maturity at the harvest (Bai et al. 2004). However, postharvest parameters are not clearly related to the presence of flavor compounds. It is mainly dependent on the metabolic and physiological process at the maturity of fruits and vegetables (Rico et al. 2007). Furthermore, proper sanitation, storage and transportation conditions (i.e. temperature and humidity) need to be considered (Plotto et al. 2006). Therefore, contamination in the raw products and attached during minimal processing determines the shelf life.

1.6 Impact of Minimal Processing on Nutrition Contents

In addition to sensory attributes, nutritional and health functional components also determine products' key quality parameters. These further rely on the climatic conditions, harvesting operations, and methods of harvesting as well as the processing steps used, such as cutting, shaping, packaging, speed of operations as churning, cooling, and mixing. Functionality of the treated products is largely dependent on the bioactive compounds and antioxidant capacity. Other important factor of the post processing is the packaging techniques. The appropriate compositions of carbon dioxide or oxygen during modified atmosphere packaging avoid unfavorable changes (Goswami and Mangaraj 2011).

1.7 Concept of Hurdle Technology

The multi-hurdle approach is the most feasible and reliable for controlling the microbial growth and it ensures the minimum reduction of food quality. Hurdle technology uses combination of preservation methods and it provide desired safety of the food products (Leistner 2000). Applying hurdle technology by coupling of pasteurization and blanching can result in complete eradication of the microorganisms. Further hurdle could be applied by refrigeration and it can further reduce chemical reaction rate. There are other potential hurdles to enhance preservation, such as reduced water activity, and lowered pH. These could be applied by adding agents, such as glucose, fructose, sodium, potassium chloride, and citric acid, tartaric acid, and benzoic acid. In addition to chemical agents, preservatives in the form of sorbates, propionates, sodium benzoate can be added for preventing the growth of pathogens. Therefore, combined techniques strengthen the efficiency of the treatment and improve quality. Moreover, it results economic gain in terms of energy, money and time. This technology has been shown promising results on sliced apple, mango, banana puree, plum, strawberries, tamarind, and passion fruit.

1.8 Fresh-Cut Fruits and Vegetables

1.8.1 Washing, Peeling, and Slicing of Fresh-Cut Fruits and Vegetables

The appearance, taste, color and texture of fresh cut fruits and vegetables are the most appealing attributes to the consumers. Fresh cut products are presently in the great demand in the Europe and North America. Fresh-cuts are preferred products due to their benefits (1) convenient to consumers, (2) available at different portion sizes,

(3) reduced labour in preparation before consumption, (4) retained nutrients and fresh aroma. All these factors are contributing to the tremendous growth of fresh-cut industry in the global markets.

Fresh-cut fruits and vegetables need to be stored in chilling conditions at around 0–5 °C. The techniques used for the processing of fresh fruits and vegetables as canning, drying, steaming do not play an essential role for enhancing the shelf life of fresh products (Kader and Mitcham 1995; Beaulieu and Gorny 2001). The limitations related to the stability of the fresh-cut products are desiccation, microbial spoilage, browning of tissues, discoloration, development of off flavour and taste. The consumers always look at these quality aspects prior to purchase.

Processing of fresh-cut fruits and vegetables require preparatory steps, such as washing, peeling, shredding, cutting. These steps result cuts, bruises and injuries to internal tissues and can cause desiccation and wilting as well as microbial and enzymatic spoilage. These injuries fasten the respiration rate, which further triggers the increased production of ethylene, senescence, and enzymatic browning.

1.8.2 Operations Affecting the Quality of Fresh-Cut Fruits and Vegetables

Most of the fresh produce requires the processing operations in order to produce the products (Siddiqui et al. 2011). These are discussed below:

1. Sorting: Sorting is the preliminary step for segregating the acceptable and non-acceptable products. It is done to remove the physiological defects from the produce. Commonly, manual sorting results in high quality results in comparison to sorting by equipment in terms of peculiar minute defects.
2. Peeling: It is one of the common operations used for fruits, such as apple, sapota, and citrus fruits; and for vegetables, such as carrots and onion. Methods used for peeling directly influence the quality parameters of the final products (Cantos et al. 2001). Peeling is usually carried out by hand or by abrasive peelers. Hand peeling provides the high quality product but often leads to expensive labour. However, abrasive peelers are also used for producing fine quality products, but they tend to damage the fresh products by causing scaring on the surface and edible portion can also be damaged.
3. Cutting: The unwanted parts of the plant based foods, such as seeds and stems need to be discarded before further processing. Therefore, trimming of the unwanted parts with eroded knives, cutters can pose a threat to the quality. The cutting tools should be cleaned and stored under good conditions. In addition, the overripe area or contaminated area should be discarded during initial sorting in order to prevent the growth of microbes and to avoid contamination of other infecting agents.

1.8.3 Factors Affecting the Washing of Fresh-Cut Fruits and Vegetables

Washing is an important step for minimally processed fruits and vegetables and the following factors need to be considered:

1. Washing: Proper washing of fresh cut fruits and vegetables is the utmost desired immediately after cutting. This step removes the dirt and some microbes present on the surface of products. Usually chlorinated water is used for rinsing the peeled fruits and vegetables. Therefore, the contact time during washing, pH and temperature of the rinsing water play a key role for assuring the quality of products (Sapers 2003).
2. Contact time: The contact period needs to be consider for an effective operation. Generally, chilled water is required for rinsing the peels and fresh-cut fruits and vegetables. Thus it is one way to cool the products before further processing and their packaging.
3. Temperature: Temperature needs to be controlled for avoiding the spoilage at preliminary step. It should be maintained at around 0 °C.
4. Chlorination: Optimum concentration of chlorine needs to be used. The concentration of chlorine should be kept between 50 and 100 ppm. However, higher concentration of chlorine can affect the quality of the peeled fruits and vegetables. Proper kits for chlorine testing should be used for controlling chlorine level in water.
5. pH: Optimum controlled pH is required for maintain the bactericidal activity of chlorinated water. If the pH rise above 7.5, the antibacterial effect would be vanished and spoilage of the products can occur due to microbial growth.

1.9 Packaging Technologies for Minimally Processed Foods

Tremendous progress has been made in the modified atmosphere packaging of fresh fruits and vegetables (Marsh and Bugusu 2007; Alzamora et al. 2000; Devlieghere et al. 2004; Al-Ati and Hotchkiss 2003). As oxygen is a prerequisite for the aerobic microorganisms' growth and replacing it with gases, such as carbon dioxide can hinder the growth of organisms. However, optimum gas compositions need to be used for each product. The use of antimicrobial packaging is a new trend (Ayala-Zavala and González-Aguilar 2010). These antimicrobial substances in packaging are released to the food product during storage, which prevent the undesirable growth of micro-organisms on the surface of food (Vermeiren et al. 2002). There are different ways of adding these antimicrobials to the food product. Either they can be incorporated as a sachet inside the packaged or surface of the packaged can be coated with the antimicrobial compounds (Ayala-Zavala et al. 2008). In addition, silver nanoparticles are coated in non-edible films and could be used.

However, WHO and European legislations need more studies before their usage in food products. The spraying of antimicrobials on the product can prevent the microbial growth and can provide improved shelf life.

1.10 Minimal Processing Techniques

The thermal treatments, non-thermal treatments, low temperature storage, applying new packaging techniques, and treated with natural antimicrobials alone or in combination are commonly used for minimally processed foods.

1.10.1 Thermal Methods

Thermal methods are can inactivate the lethal organisms and enzymes. It can form aromatic and flavor compounds. However, heating can also destroy the sensitive components like vitamins and health functional compounds (Bansal et al. 2014). Thus, optimum heat treatments can make the food microbiologically safe and nutrient enriched. High temperature short time (HTST) can be used to achieve the target.

1.10.2 Coupling with Non-thermal Methods

Non-thermal processing techniques are emerging in the food industry. These techniques are extended their potential to food preservation with limiting losses of the nutritional and sensory characteristics. These are high hydrostatic pressure, pulsed electric fields, high intensity pulsed light, pulsed white light, high power ultrasound, oscillating magnetic fields, irradiation, and microwave processing. All these techniques have provided a reliable alternative for processing of liquid foods, such as beverages, juices, soups, purees along with solid whole fruits, vegetables and packaged foods. Numerous reports have been published on the high hydrostatic pressure and pulsed electric fields for inactivating the lethal micro-organisms and enzymes. Apart from their microbial inactivation, these are used to extract bioactive compounds, such as polyphenols, flavonoids, hydroxycinnamic acids and. These are termed as non-thermal methods and temperature of processing remained within 30–55 °C. The low temperature safeguards the heat labile components, such as vitamin C, and pigments (e.g. carotenoids).

Pulsed electric fields The concept of treating foods with pulsed electric fields was introduced in 1960. Initially the technique was confined to kill microorganisms with optimized parameters such as electric field, pulse shape, pulse width and treatment time.

In PEF processing, food products are subjected to a high voltage electrical field such as 20–70 kV/cm for a few microseconds.

Earlier the principle of electroporation was proposed stating puncturing the cell membrane of the organisms. Afterwards, PEF was tested on the juices instead of the buffer solutions to inactivate the microorganisms and to have the increased shelf life of fruit juices. PEF technology inactivates or kills a number of vegetative bacteria however; it is not effective to inactivate the spores at ambient temperatures (Yousef and Zhang 2006; Park et al. 2014). During the last decade, the new scope of PEF has been evolved for enhanced mass transfer. PEF was advanced for inactivating or killing of organisms in the juices to an accepted level, and it was diverted to apply for retaining the nutritional parameters. Since PEF is one of the non-thermal processing techniques, the temperature remains between 30 and 50 °C that enables the significant retention of nutrients. There are several reports, which described the potential of preservation or pasteurization of a variety of liquid foods; however, it still seems premature to recommend its use in fresh cut fruit and vegetable products.

A few recent studies have also been carried to assess its effect of PEF on retaining the quality meat products. For example, O'Dowd et al. (2013) compared the impact of PEF [(electric field strength: 1.1–2.8 kV/cm; energy density: 12.7–226 kJ/kg), frequency (5–200 Hz) and pulse number (152–300)] and conventional treatments on quality characteristics of post rigour beef muscle. They reported that some PEF treatments increased weight loss and affected the size of myofibrils. In some cases, the PEF induced reversible changes in cell membranes, however, did not affect the instrumental texture profile of beef.

High pressure processing (HPP) It is also referred to "high hydrostatic pressure processing" or "ultra-high pressure processing", in which the elevated pressures (up to 600 MPa), with or without the addition of external heat (up to 120 °C), is used to achieve microbial inactivation or to alter food attributes (Park et al. 2014) without affecting flavor compounds and vitamins. It is mainly based on the inactivation of the microbial and enzymatic spoilage by exerting pressure. High pressure induces stress on the membranes and prevents them to come in their active state (Toepfl et al. 2006). However, the microbial resistance to pressure varies significantly as per the range of the applied pressure and temperature, treatment period, and types of microbes. Various food products such as jams, jellies, fruit dressings and sauces, toppings, yoghurt, and grapefruit, avocado and orange juice are subjected to HPP (Pasha et al. 2014). It also effects texture of the foods and various researchers are in the process of overcoming hindering aspects in order to make usage of the HPP technology (Hayman et al. 2004). Interestingly, HHP is used to restructure the food proteins and it results in denaturation, aggregation or gelation of the protein.

As discussed earlier, the microbial infection and enzymatic browning have been identified as major challenges in fresh cut processing, which directly influence the consumers' acceptance. A recent review on effect of HPP on quality-related enzymes in fruit and vegetable products revealed that HPP inactivates vegetative

microbial cells at ambient temperature conditions without affecting the nutritional and sensory qualities. Enzymes such as polyphenol oxidase (PPO), peroxidase (POD), and pectin methylesterase (PME) are highly resistant to HPP and are at most partially inactivated under commercially feasible conditions, although their sensitivity towards pressure depends on their origin as well as their environment. Polygalacturonase (PG) and lipoxygenase (LOX) on the other hand are relatively more pressure sensitive and can be substantially inactivated by HPP at commercially feasible conditions. The retention and activation of enzymes such as PME by HPP can be beneficially used for improving the texture and other quality attributes of processed fruit and vegetable products as well as for creating novel structures that are not feasible with thermal processing (Terefe et al. 2014).

A recent review on high pressure processing of fresh meat published by Ma and Ledward (2013) summarized the facts and figures of its use in meat processing that are (1) At about 200 MPa actomyosin denatures and at 400 MPa myoglobin denatures, (2) At about 400 MPa and above the lipids in meat become more susceptible to oxidation, (3) At 100–150 MPa and ambient temperature pre-rigor meat is tenderized, and (4) At 100–200 MPa post-rigor meat is tenderized as the temperature is raised to 60 °C.

Natural antimicrobials Although synthetic antimicrobial and antioxidant agents are approved in many countries, the use of natural safe and effective preservatives are in demand by the consumers and producers (Ortega-Ramirez et al. 2014). Therefore, many European and Asian countries are exploiting natural ingredients that can protect the food against the deterioration. There are a great number of natural antimicrobials derived from animal, plant, and microbial sources. The bioactive functional compounds known as secondary metabolites, obtained from plant sources, are considered as good alternatives to synthetic antimicrobial and antioxidant food additives (Silva-Espinoza et al. 2013; Ortega-Ramirez et al. 2014). These constitute polyphenols, tannins, and flavonoids, which are mostly derived from plants and their antimicrobial and antioxidant in vitro effects have been reported in many publications in the last decade (Manas and Pagán 2005; Inbaraj et al. 2010; Krishnaiah et al. 2011; Martins et al. 2013). The antimicrobial and antioxidant properties of bioactive molecules are mainly due to their redox properties, ability to chelate metals, and quenching reactive species of singlet oxygen (Krishnaiah et al. 2011). These compounds can be added to beverages, sauces, meat like pork, and fish to prevent their spoilage. Compounds can either be coated or sprayed on the food products for their quick absorption and action. It is also important to keep the desired sensory properties when additives are used (Skandamis and Nychas 2000). However, the selection of the plant sources to extract these compounds must be guided for the safe use of food additives. Some key issues must be considered during the application of these natural antimicrobial agents into food products. The form of the antimicrobial, the type of food, storage conditions, types of processes used, and the target microorganism(s) are some of the important factors that could affect the efficacy of these agents (Davidson et al. 2013).

1.11 Conclusions

In the era of modern technology and changing in consumers' demand shifted the food habits and consumption. Consumers inclined towards the food products, which have high nutritional values along with freshness, safety, and extended shelf life. In the near future, the minimally processed foods are to be engulfed the global markets. The introduction of latest and reliable technologies such as non-thermal treatments assists in minimizing the quality degradation of foods and making full usage of the available resources.

The market of minimally processed foods has grown rapidly in recent years due to the health benefits and convenience associated with these foods. Its growth has increased the awareness regarding microbiological and physiological aspects associated with the quality. The consumerism tendency depends on multi-factors as nutritional value, simplicity, safety, and convenience. All these characteristics must be considered in minimal processing. Minimally processed foods have formed the well-established market and engulf the capital investment. The various schemes of research and development targeting the agricultural products have been established that provides long life to short life perishable and improves the quality of short life foods.

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Chapter 2
Hurdle Technology in Food Preservation

Mohammad Shafiur Rahman

2.1 Introduction

Most of the food products in the market are preserved (i.e. retained its stability) based on more than one hurdle or preservation method. In order to determine the food stability, two questions need to be asked: what target attribute(s) needs to be achieved in the microbial, chemical, bio-chemical and physical changes; and what is the required time frame of stability? When considering stability, the microbial and chemical safety aspects must be considered first before sensory properties. The microbial stability and safety of the most traditional and novel foods is based on a combination of several preservation factors (called hurdles), and the microorganisms present in food are unable to overcome. This is illustrated by the so-called hurdle effect, first highlighted by Leistner (1978). The critical limits are being used by the industry when each hurdle such as heat treatment, water content, pH and storage temperature is applied alone. Fundamental based theoretical concepts of F-value (hurdle: heat treatment), water activity (hurdle: water content) and glass transition (hurdle: glassy state; depending on water, storage temperature, and structure) are the most successful in determining food stability during food processing and storage. These concepts (i.e. each hurdle) are usually applied to specific types of products, for examples F-value to canned foods (i.e. high moisture); and water activity and glass transition for dried and frozen foods. The F-value is based on commercial sterility, water activity by state of water (i.e. bound or free) and glass-rubber transition by structural mobility. However, more than 60 hurdles may involve in food preservation (Leistner 2000a). The details of the important hurdles used in establishing food stability are discussed in the IFT/FDA Report (2003) and Leistner (2007).

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In achieving the desired safety by only one hurdle, high severity in processing needs to be applied. This caused significant damages to the nutritional and sensory quality of foods. For this reason, it is important to have multi-hurdles approach for developing safe and wholesome food products. The hurdle effect has fundamental importance for the preservation of foods, since the hurdles provide a control to microbial spoilage, food-poisoning and other undesired changes. The advantages of hurdle concepts are (1) it can avoid the severity of one hurdle for preservation, (2) it can give synergy of combination, and (3) many of the hurdles come from past experience (i.e. tradition or culture). Currently huge numbers of products are being developed based on the multi-hurdles. The combinations and the levels of hurdles are determined based on the empirical experiments. However, it is a challenge to food scientists and engineers to have unified concept or approach for determining food stability considering multi-hurdles, such as heat treatment, water content, pH, salt, spices, preservatives, packaging and storage temperature. Stability map was proposed based on the state diagram (i.e. states and/or phases of a food as a function of water or solids content and temperature) (Levine and Slade 1986; Rahman 2012). Recently macro-micro region concept in the state diagram has been proposed and relative stability map is postulated in the 13 micro-regions. In order to achieve safety, the proposed micro-region concept showed potential to combine multi-hurdles, or to provide a guide on the hurdles need to be used in each micro-region (Rahman 2009). The objective of this chapter is to highlight the recent development in achieving food stability by intelligent use of multi-hurdles and theoretical concepts.

2.2 Guide Lines for pH and Salt

2.2.1 pH Value

The minimum pH for the growth and toxin production of microorganisms are compiled by IFT/FDA Report (2003) and Rahman (2007). The literature tabulations include a pH lower than 4.6 to inhibit the growth of many pathogens and this limit is considered as safe or low risk (Brown and Booth 1991). It is generally accepted that the limiting pH of 4.6 provides a good margin of safety against the hazards of *botulism* in acidified foods, and such products are given relatively mild heat treatment. The critical limit of pH 4.6 is commonly used to categorize the low risk and high risk foods. Based on a comprehensive review of the literature, the IFT panel concluded that a pH of 4.6 is appropriate to control spore-forming pathogens and a pH of 4.2 is appropriate to control vegetative pathogens (IFT/FDA Report 2003).

2.2.2 Salt (i.e. Sodium Chloride)

Salt is one of the most common preservatives. Life at high salt concentration is energetically expensive. Oren (2011) identified thermodynamic limits to microbial life at high salt concentration. They identified that 346 g/L (i.e. 34.6 %) was the

limit to stop all microbial process, thus only salt as a hurdle could be impossible to implement due to the negative impact on health and sensory. For this reason, most of the cases salt is used in combination with other hurdles. Most processed meat products contain sodium chloride from 2.8 % in cooked sausages to 4.5 % in cured meat products (Komarik et al. 1974) and have been maligned as a heavy salt contributor to the diet. However, in many products salt in combination with other hurdles showed high potential.

2.3 Progress in Developing Guidelines

The stability guidelines are mainly based on the pH, water activity, and thermal processing. FDA's Good Manufacturing Practice Regulations governing the processing requirements and the classification of foods are shown in Fig. 2.1 (Johnston and Lin 1987). Low acid (i.e. high pH) foods packaged in hermetically sealed containers must achieve commercial sterility conditions either by retorting or combined treatment of pasteurization and water activity or a combined treatment of pasteurization and acidification. It could be seen that pH 4.6 and a_w 0.85 are the critical limits. In 1962 the US Public Health Service in the "Food Service Sanitation Manual" issued the potentially hazardous food (PHF) as any perishable food which consists in whole or in part of milk products, eggs, meat, poultry, fish or other ingredients capable of supporting the rapid and progressive growth of infectious or toxigenic microorganisms. The progress of the definition of PHF is discussed in the IFT/FDA Report (IFT/FDA 2003). FDA Food Code in 1999 defined PHF food as it

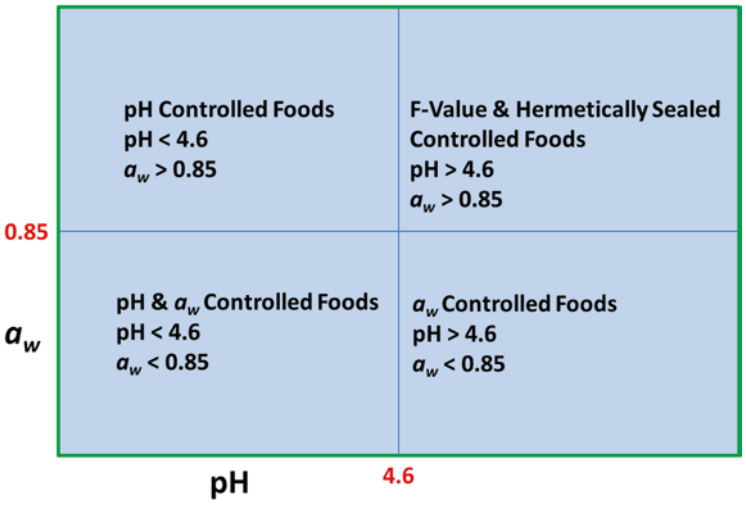

Fig. 2.1 FDA Good Manufacturing Practice Regulations governing processing requirements and classification of foods (Adapted from Johnston and Lin 1987)

Table 2.1 Control of spores: product treated to control vegetative cells and protected from recontamination

	Critical pH Values		
Critical a_w Values	pH ≤ 4.6	4.6 < pH < 5.6	pH 5.6
$a_w \leq 0.92$	Non-TCS	Non-TCS	?
$0.92 < a_w < 0.95$	Non-TCS	Non-TCS	?
$a_w > 0.95$	Non-TCS	?	?

Note: ? means stability is question, thus number of measures need to be taken

Table 2.2 Control of vegetative cells and spores: product not treated or treated but not protected from recontamination

	Critical pH Values			
Critical a_w Values	pH < 4.2	4.2 < pH < 4.6	4.6 < pH < 5.0	pH > 5.0
$a_w < 0.88$	Non-TCS	Non-TCS	Non-TCS	Non-TCS
$0.88 < a_w < 0.90$	Non-TCS	Non-TCS	Non-TCS	?
$0.90 < a_w < 0.92$	Non-TCS	Non-TCS	?	?
$a_w > 0.92$	Non-TCS	?	?	?

Note: ? means stability is question, thus number of measures need to be taken

must be kept cold or hot, because the food (i.e. temperature controlled for safety, TCS) has the necessary intrinsic factors to support the growth of pathogens. The TCS foods require time/temperature control to limit pathogen growth or toxin formation that constitutes a threat to public health. A science-based framework was proposed by the IFT/FDA panel (IFT/FDA Report 2003). The framework contains two steps:

- Step 1: Was the food treated to destroy vegetative cells of potentially pathogens and packaged to avoid recontamination? If yes, position your product in Table 2.1 according to its pH and water activity (a_w). If not, position your product in Table 2.2 according to its pH and a_w.
- Step 2: If the food is classified as a non-TCS food according to Step 1 above, it may be stored and held safely without regard to time or temperature. If the need for time/temperature control is questionable, the food should be held either hot or cold for safety or subjected to a product assessment as the next step in determining the appropriate classification.

The product assessment was performed based on the factors, such as ingredients, processing, change of acids used to lower pH, preservatives, and formulation. The final decision on the hurdles could be based on challenge testing and available predictive models. The panel used their proposed framework to determine its applicability to a specific example(s) from selected class of food product categories. Additional examples of the determination of TCS are provided in the report developed by Texas Department of State Health Services (TCS Guidance 2006). They also identified the pathogens of concern for different classes of food products and potential hurdles alone or combination to be used. Scientific sound criteria for

determining whether foods require time/temperature control for safety could consider the interaction of pH, a_w and other factors from microbial growth models. For example, USDA pathogen model could identify the critical boundary for growth of specific bacteria when both pH and a_w are used. The panel pointed that framework should be validated for a broad variety of products, and predictive models of pathogens as a function of several parameters, such as packaging atmosphere, redox potential, pH, a_w, preservatives and ingredients should be developed. In addition, synergistic factors and variations of results in the real product and challenged test should also be explored.

2.4 Concepts of Food Stability Determination

2.4.1 F-Value

In 1795 Nicolas Appart, a chef took up a challenge and established a theory that if fresh foods were put in airtight containers and sufficient heat applied, then food would last longer. He proposed his preservation method after 14 years of experimentation without understanding the role of bacterial spoilage. A theoretical understanding of the benefits of canning did not come until Louis Pasteur observed the relationships between microorganisms and food spoilage after 50 years later (Rahman 2009). The sterilization of canned foods has a long tradition and it is most likely that it will continue to be popular because of its convenience and extended shelf-life (1–4 years at ambient temperature).

The time of sterilization process is estimated based on F-value concept. The F-value was originally developed by Bigelow et al. (1920) and subsequently by Ball and Olson (1957). By the 1860s the time required to process food in can was reduced from 6 h to 30 min through numbers of inventions and improvements (Simpson et al. 2012). The inactivation target in sterilization process depends on the types of heat resistance bacteria and pH of foods. It is possible to classify food products into three groups according to pH: low-acid ($pH \geq 4.6$), medium-acid ($3.7 \leq pH \leq 4.6$), and high-acid foods ($pH \leq 3.7$). The target microorganism in the thermal processing of low-acid food ($pH \geq 4.6$) is *Clostridium botulinum*. The processing time based on first order kinetics can be estimated as (Bigelow 1921; Singh and Heldman 2009):

$$t = -\frac{1}{k}\ln\left(\frac{N_F}{N_o}\right) = \left(\frac{D}{2.303}\right)\ln\left(\frac{N_F}{N_o}\right) \tag{2.1}$$

where k is the destruction rate (s^{-1}), N_o and N_F are the initial and final numbers of micro-organisms, and D is the decimal reduction time (s), respectively. Equation (2.1) for microbial death indicates that final concentration tends to zero when time tends to infinity, thus it would not be possible practically to reach a final concentration of zero for the target micro-organism. Considering this point, the commercial

sterilization criterion should be defined so that it is possible to design a process that is safe but occurs within a finite time and which is economically and practically feasible (Simpson et al. 2012). According to Stumbo (1973) the commercial sterilization criterion was established arbitrarily. The commercial sterilization criterion states that the minimum thermal process should reduce initial micro-organism concentration by 10^{12}. This is well known as 12*D* concept or "botulinum cook". Teixeira (2002) discussed the origins of the 12*D* concept and outlined the original work of Esty and Meyer (1922). They concluded that Stumbo (1948) was the first to recognize the logarithmic nature of time temperature curve. The commercial sterilization was used for several reasons (1) safety margins, (2) cooking requirements, and (3) to prevent the growth of thermophilic spoilage microorganisms. The probability argument says, in 12*D* treatment there will be one spore in 10^{12} cans (Singh and Heldman 2009). Considering 100 million cans consumed per day, an estimate over a 100-year period worldwide consumption will be 3.65×10^{12} cans and the 12*D* criterion would predict three to four outbreaks every 100 years (Simpson et al. 2012).

The processing time to achieve 12*D* can be estimated when D_T value of target micro-organism at the temperature T is known. However, the processing time varies with the size of a can. Considering $D_{121.1} = 0.21$ min for *C. botulinum*, one spore per g and can size of 0.1 L (density: 1 g/cm^3), the processing time (t) to achieve 12*D* is 2.94 min from Eq. (2.1) (Simpson et al. 2012). Similarly if the can size is 5 L, the processing time is 3.29 min. Since thermal process could not be performed at a specific temperature instead a varied temperature range during heating and cooling time, thus thermal death time, F_r is defined for processing as (Holdsworth and Simpson 2008):

$$F_r = \int_0^t 10^{\frac{T-T_r}{z}} dt \tag{2.2}$$

where F_r is the processing time at a reference temperature (s), T_r is the reference temperature (°C) and z is the thermal constant or z-value. If reference temperature T_r is 121.1 °C, then F_r is termed as F_o as:

$$F_o = \int_0^t 10^{\frac{T-121.1}{z}} dt \tag{2.3}$$

Currently, a common commercial sterilization treatment for *C. botulinum* F_o is in the range of 6–8 min, although some companies use F_o of 10 min or higher. Considering this processing time, 5 L can size and the minimum time requirement (6 min) at 121.1 °C, indicated 1.335×10^{-25} spores per package. Applying the probability concept, we should expect one outbreak in several billion years (to be precise, one hundred thousand billion years). In fact, at least in the past 50 years no outbreak has been directly related to the sterilization criterion (Simpson et al. 2012). However, there is no theoretical method available for the prediction of F_o, if other hurdles are used in combination.

2.4.2 Water Activity

W.J. Scott, an Australian scientist, proposed that the active water could be much more important to the stability of a food than the total amount of water present. The legacy of Scott allowed scientist to develop generalized rules or limits for the stability of foods using water activity (Scott 1953). In general the rules of water activity concept are (1) food products are most stable at their "BET-monolayer" content or "BET-monolayer water activity" and unstable above or below BET-monolayer; (2) there are a critical water activity limit for a specific micro-organism or a class of micro-organism for their growth or toxin production, and biochemical reactions (Scott 1953; Labuza et al. 1970). For example, there is a critical water activity level below which no microorganisms can grow. Pathogenic bacteria cannot grow below a water activity of 0.85, whereas yeasts and molds are more tolerant to reduced water activity, but usually no growth occurs below a water activity of about 0.6. Labuza et al. (1972) proposed the food stability map based on the water activity concept containing growth of micro-organisms and different types of bio-chemical reactions. In the recent food stability map, Rahman (2009) showed the trends of microbial growth, bio-chemical reactions and mechanical characteristics in the three zones of water activity (zone 1: BET-monolayer, zone 2: adsorbed multi-layer, zone 3: matrix or solvent water) (Fig. 6.5). In fact, the BET-monolayer could be only achieved in the cases of dried foods. The limitations of water activity concept are reviewed by Rahman (2010). However, food industries are now widely used this concept for determining the stability of their dried products.

2.4.3 Glass Transition

Considering the limitations of water activity concept, the hypothesis of glass transition concept was put forward. White and Cakebread (1966) first highlighted the importance of the glassy state of foods in determining its structural stability. The significant applications of the glass transition concept emerged in food processing in the 1980s, when Levine and Slade (1986) and Slade and Levine (1988) identified its major merits and wide applications. The rules of the glass transition concept are (1) the food is most stable at and below its glass transition (i.e. T_g or T_g'), and (2) the higher the T-T_g or T/T_g (i.e. above glass transition), the higher the deterioration or reaction rates (Levine and Slade 1986). Detailed Reviews on the food stability in relation to glass transition, molecular relaxation and mobility are available in the literature (Champion et al. 2000; Le Meste et al. 2002; Rahman 2006, 2010). It is clear from the literature that all experimental results could not be explained by the above rules (Rahman 2009; Levine and Slade 1986), thus further developments are necessary. The limitations of water activity and glass transition concepts would not invalidate the concepts completely rather make it difficult to apply universally. The water activity concept is based on the binding nature of water molecules in the matrix.

When water is bound (i.e. unavailable to take part in reactions) to the solid matrix or non-solvent, then no deterioration reactions could be expected. The glass transition concept is based on the molecular mobility of the reacting components at micro-level in a matrix, thus diffusion of the reactants through the system is very slow and stability is achieved. Thus a successful combination of water activity and glass transition could open more precise and unified determination of stability criteria (Rahman 2010).

2.4.4 Critical Temperature Concept and Molecular Mobility

It is expected that there should be a break in the plot of k (i.e. reaction rate) versus T/T_g (i.e. change in slope between above and below the critical ratio) at T/T_g equal to 1, if glass transition concept is valid or X_w/X_b equal to 1, if water activity concept is valid. Buitink et al. (2000) measured molecular mobility by ST-EPR and ^{1}H-NMR, and observed two distinct changes: first one minor shift just close to T_g and second abrupt decrease due to solid-like to liquid-like defined as T_c. In the case of sugars, T_c was observed at 17–35 °C higher than T_g and for biological materials it was more than 50 °C. This variation was also explained by the density of hydrogen bond and molecular packing measured by FTIR. This higher T_c was also correlated with the observed collapse or softening of sugars at 10–17 °C above glass transition (Levine and Slade 1988; Roos 1995; Sun et al. 1996) and crystallization above 30 °C. It is generally believed that crystallization over practical time scale occurred above glass transition, although some report showed it was below 30 °C than glass temperature (Le Meste et al. 2002). α-amylase was more stable in rubbery matrices of lactose or trehalose than in a glassy PVP matrix and the protective efficiency of saccharides, maltodextrins and PVPs did not increase with their respective glass transition temperature (Rossi et al. 1997; Terebiznik et al. 1998). In addition dielectric and other spectroscopy determine α, β and γ relaxations below glass transition (Adrjanowicz et al. 2009). However it is not clear how these could be related or linked to determine the stability of foods. Considering the fact that glass transition is not the critical limit, Rahman (2010) tested the hypothesis that there is a critical temperature as a ratio of T_c/T_g (T_c is the critical temperature) which could vary with moisture content. Above the critical temperature, an increase in the water content or temperature significantly increased the reaction rate while below the critical temperature the rate was relatively less affected by water content and temperature. He observed values of T_c/T_g varied from 0.78 to 1.5 depending on the types of reaction and the matrices. In some instances, the values of T_c/T_g were close to 1.0 indicating only glass transition could explain the process. Moreover, the deviations of T_c/T_g from 1 explain why in many instances in the literature both stability and un-stability were observed above and below glass transition. The glass transition by thermal or mechanical relaxations measure mobility in a 20–300 nm range, while other relaxation techniques, such as Nuclear magnetic Nuclear Magnetic Resonance (NMR) measures the molecular relaxation in a 1–2 nm range (McBrierty and Packer 1993).

Recently, tremendous progress has been achieved in understanding multidimensional aspects of the molecular mobility. Although it is not yet very clear how these knowledge could by applied university in determining the stability of foods.

2.4.5 State Diagram

The glass transition concept was further advanced by developing state diagrams for foods. A state diagram is a stability map of different states and phases of a food as a function of water or solids content and temperature. Most probably, Levine and Slade (1986) presented the first state diagram in the food science literature by illustrating glass line, freezing curve, and intersection of these lines as T_g'' by extrapolation of the extended freezing curve by maintaining similar curvature. The main advantage of drawing a map is to help understanding the complex changes when the water content and temperature of foods are changed. It also assists in identifying stability of foods during storage as well as selecting a suitable condition of temperature and moisture content for processing. The state diagram based on freezing curve and glass transition provided four macro-regions: region I (i.e. below glass transition), region II (above glass transition and below maximal-freeze-concentration, i.e. completely frozen), region III (above maximal-freeze-concentration condition and below freezing curve, i.e. partially frozen), and region IV (i.e. above glass transition and above freezing curve) (Levine and Slade 1986). Rahman (2006) combined water activity and glass transition concepts in the state diagram by plotting BET monolayer as a function of temperature. This makes four regions: below BET-monolayer, one above and one below; and above BET-monolayer, one above and another below. In the literature it was emphasized that a combination of water activity and glass transition concepts could be a powerful tool in predicting food stability. The approaches to combine both concepts are reviewed by Rahman (2010, 2012). However, Rahman (2006) combined glass transition and water activity concepts in the state diagram by plotting BET-monolayer values as a function of temperature.

2.4.6 Macro-Micro Region in the State Diagram

Using state diagram, Rahman (2009) hypothesized 13 micro-regions having the highest to the lowest stability based on the location from the glass and BET-monolayer lines (Fig. 2.2). For example, region-1 (relatively non-reacting zone, below the BET-monolayer line and glass line) is the most stable and region-13 (highly reacting zone, far from BET-monolayer line and glass line) is the least stable. The stability decreased as the zone number increased. Applications of this hypothesis in food processing are presented by Rahman (2006, 2010, 2012). Schebor et al. (1995) studied sucrose hydrolysis in the micro-regions 1 and 2, and evidenced the validity of the hypothesis. Advantages of micro-region concept are as follows

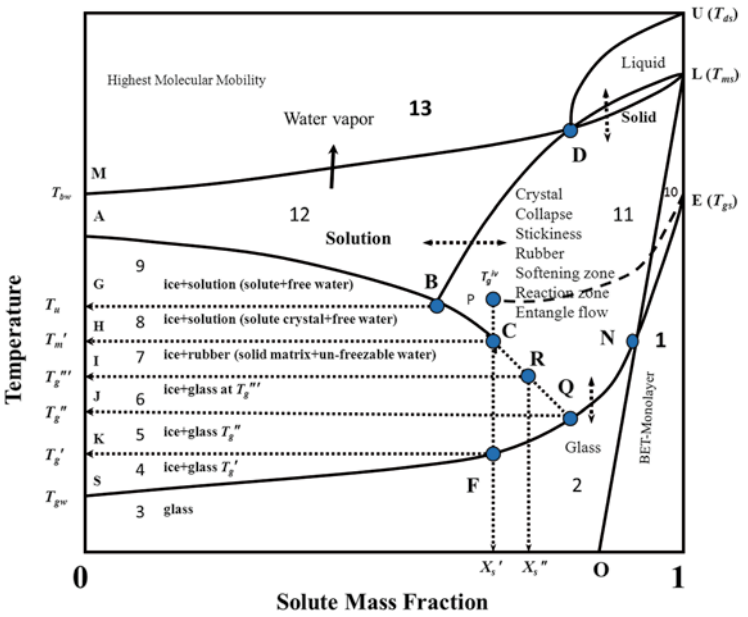

Fig. 2.2 State diagram showing different regions and state of foods [updated from Rahman (2006, 2009)] T_{ds}: solids-decomposition temperature, T_{ms}: solids melting temperature, T_{gs}: solids–glass transition temperature, T_g^{iv}: end of solids-plasticization temperature, T_{gw}: glass transition of water, T_u (solute crystallization temperature during freeze-concentration), T_m' (maximal-freeze-concentration condition, i.e. end point of freezing), T_g''' (glass transition of the solids matrix in the frozen sample as determined by Differential Scanning Calorimetry (DSC)), T_g'' (intersection of the freezing curve to the glass line by maintaining the similar curvature of the freezing curve), and T_g' (glass transition at maximal-freeze-concentration, i.e. at the end point of freezing), T_{bw}: boiling temperature of water (Rahman 2012)

(1) stability rules could be developed for each micro-region (i.e. narrow moisture and temperature range) as compared to the macro-region (i.e. broad moisture and temperature region), and (2) the states or phases of the material could be identified in each micro-region. A reference point could be identified where BET-monolayer line and glass line intersect and any location in the state diagram could be assessed in relation to the reference point.

2.5 Progress in Microbial Reaction in Relation to Hurdle Concept

Hurdles are deliberately combined to improve the microbial and chemical stability, and the sensory quality of foods as well as their nutritional properties and economic cost. Thus it improves the total quality of foods by application of an intelligent mix

of hurdles (Leistner 1985, 2000b). The main advantage of the hurdle technology is its synergistic effect (i.e. non additive). Previously hurdle technology (i.e., a combination of preservation methods) was used empirically without much knowledge of the governing principles. Progress in principles of the major preservative factors on the physiology and behavior of microorganisms in foods could allow more intelligent applications of hurdles (Leistner 2000b). These are: homeostasis, metabolic exhaust, and stress reactions. Homeostasis is the tendency to achieve uniformity and stability in the internal status of organisms (Gould 1988). For instance, the maintenance of a defined pH is a prerequisite and feature of living cells, and this applies to higher organisms as well as microorganisms (Haussinger 1988). When homeostasis of bacteria is altered, the bacterial cells react by spending their energy in maintaining their physiological status rather than in multiplying, thus repair needs more energy. In this case microorganisms remain in the lag phase or even die before their homeostasis is reestablished by repair (Leistner 1995a). Energy restrictions for microorganisms are caused by anaerobic conditions, such as vacuum or modified atmosphere and low a_w, pH and redox potential, and these act synergistically in combination when applied in foods (Gould 1995).

Metabolic exhaustion is the "auto-sterilization". It was first observed that in a mildly heated sausage inoculated with *Clostrial* spores and adjusted to different water activity by addition of salt and fat, and stored 37 °C. *Clostrial* spores surviving during the heat treatment vanished in the product during storage, especially unrefrigerated (Leistner and Karan-Djurdjic 1970). Further experimental evidence showed that auto-sterilization occurred in the unrefrigerated conditions, and more hurdles accelerated metabolic exhaustion (Leistner 2000b). More examples of "auto-sterilization" are presented by Leistner (2007). The traditional "air-dried" fermented sausages from Germany showed a good record of safety due to the fermentation at low temperature (<15 °C) and to extensive aging, which was compensated the requirement of higher levels of acids, and antimicrobial nitrite (Lucke and Vogeley 2012).

Some bacteria become more resistant or even more virulent under stress (i.e. stress reaction), since they generate stress shock proteins. The synthesis of protective stress shock proteins is induced by heat, pH, a_w, ethanol, and oxidative compounds as well as by starvation. Therefore, multi-target preservation of foods could be the key to avoiding synthesis of stress shock proteins, which otherwise could jeopardize the microbial stability and safety of hurdle technology (Leistner 1995b). Nevertheless, further research in stress shock proteins and different mechanisms that switches them on or could inactivate them warranted, in relation to hurdle technology (Leistner 2007).

The multi-target preservation of foods should be the ultimate goal for a gentle but most effective preservation of foods (Leistner 1996). Leistner (2000b) proposed that food microbiologist could learn from pharmacology and medicine. For example, at least 12 classes of biocides are already known which have different targets, and sometimes more than one, within microbial cell. Often the primary target is the cell membrane and it becomes leaky due to the disruption of cell wall.

In addition, biocides also impair synthesis of enzymes, proteins, and DNA (Denyer and Hugo 1991). Multi-drug attack has proven successful in the medical field to fight bacterial infections (i.e. tuberculosis) as well as viral infections (i.e. aids), thus a multi-target attack on microorganisms should also be a promising approach in food microbiology (Leistner 2000b).

Leistner (2007) provided an example of hurdle technology in the case of Indian *paneer*. It is a traditional cottage-cheese-type product fried in cubes with oil and onions and sauce containing salt, spices, and often tomatoes are added. However, *paneer* spoils bacteriologically within 1–2 days at room temperature (which in India can reach 35 °C), and this is a strong drawback for its industrial production. Sterilized paneer in cans showed severe sensory limitations with regard to flavour, texture and color. Table 2.3 shows how hurdle technology can use to develop paneer with long shelf life. Another example on the La Chang (i.e. a meat product in China) is also presented by Leistner and the combinations of hurdles and the shelf life are shown in Table 2.3.

Table 2.3 Examples of hurdle products

Product	Hurdles	Shelf-life
La Chang (meat) China	a_w: 0.85–0.70	2–3 months
	pH: 5.9–5.7	
	NaCl: 3–5 %	
	Sugar: 4–20 %	
	Refrigeration: No	
	Total count < 10^6/g	
La Chang (meat) China	a_w: 0.85–0.70	4–5 months
	pH: 5.9–5.7	
	NaCl: 3–5 %	
	Sugar: 4–20 %	
	Packaged: vacuum	
	Refrigeration: No	
	Total count < 10^6/g	
Fresh Paneer (India)	Storage: 35 °C	1–2 days
Paneer (India)	a_w: 0.97	Several weeks
	pH: 5.0	
	F_o: 0.8 min	
	Storage: 35 °C	
Paneer in gravy (India)	a_w: 0.95	2 weeks (Storage: 45 °C)
	pH: 5.0	1 month (Storage: 30 °C)
	F_o: 0.8 min	3 months (Storage: 15 °C)
	Potassium sorbate: 0.1 %	

Summarized from Leistner (2007)

2.6 Prediction for Multi-hurdles

In predicting or modelling stability, two approaches could be used in identifying the boundary or limit of the growth/no-growth (reaction or no-reaction) within a time frame, and then predicting the rate of growth or reaction within the growth or reacting region. Bigelow (1921) developed a mathematical model to describe the logarithm nature of thermal death. Nevertheless it was not until the 1980s when mathematical models predicting the behavior of microorganisms experienced a great development. A new field emerged in the food microbiology area: predictive microbiology. Different types of empirical growth models for microorganism are widely used. These are specific to the types of microorganism, physico-chemical properties of food, and the used hurdles. Davey et al. (1978) developed thermal inactivation rate (i.e. ln k) of *Cl. Botulinum* as a linear function of $1/T$, pH and pH^2. Similarly Cerf et al. (1996) also developed the regression correlations of ln k as a function of 1/T, pH, pH^2, and a_w. The non-monotonous changes of pH and a_w make it more difficultly to predict the effect of hurdles in combination. Velugoti et al. (2011) generated growth data of *Salmonella* in sterile pork at various isothermal conditions, and dynamic models were developed within storage temperature (10–45 °C).

In 1970s the "probability model" for the prediction of germination of spores, population growth, survival, and toxin production within a specified period of time under defined conditions of storage and product composition was emerged (Carrasco et al. 2012). The "growth/no-growth" or "interface" modeling are progressed. One of the first attempts to Growth/no-Growth (G/NG) modeling was developed by Pitt (1992). He related the boundary by an empirical equation with the temperature and water activity limits for *Aspergillus* spp. growth. Carrasco et al. (2012) reviewed the methodology of development of a probability or growth/no-growth (G/NG) models. The logistic regression approach has been widely adopted for probability and G/NG modelling. In general, probability models are devoted to the data which can be measured as "positive" or "negative". For example, if we consider the variable "detection of toxin", only two responses are possible: "detectable" or "not detectable" and responses can be coded as 1 (positive response) or 0 (negative response), or even better, if response replicates are obtained, a number between 0 and 1 can be given to the response, calculated as the average of the scores (0 or 1) of the replicates. The number obtained is considered as the probability of occurrence of the phenomenon studied. This probability can be related to independent variables such as temperature or pH by some mathematical function using regression techniques. In logistic regression, the probability (P) can be expressed as "logit" as:

$$logit\,P = \log\left(\frac{P}{1-P}\right) \tag{2.4}$$

Mertens et al. (2012) developed G/NG model by linear logistic regression and *logit* was correlated as a function of a_w, pH, sodium chloride and acetic acid. A simplified

G/NG model conceptually derived from the Gamma model. Logit was related to the variables or factors in order to determine the boundary. Polese et al. (2011) developed G/NG boundary using gamma function and observed a limited numbers of fail dangerous prediction, thus he suggested simplified G/NG model could be used as a first estimate method when experimental data are missing or insufficient. In addition, a practical time frame usually used to generate the boundary data, thus it ignores stability for longer period. In general, extrapolation in prediction, especially in foods, is not straightforward because of the complexity of the food matrix (Pinon et al. 2004).

2.7 Conclusion

Currently most of the stable food products are based on more than one hurdle. Examples of these hurdles are thermal treatment, moisture, salt, low temperature storage, and preservatives. It is a challenge to the food scientists and engineers to have unified concepts for determining food stability. The individual assessment of each product can be performed using logical tree based on their hurdles as proposed by IFT/FDA. The fundamental based prediction or the required rules for determining stability of multi-hurdle foods are limited, thus empirical approaches based on the specific experimental data are mainly used. Theoretical concepts of F-value, water activity and glass transition are the most successful in determining food stability criteria for thermal treatment, moisture content, and moisture-temperature structure control, respectively. The water activity and glass transition concepts are combined in the state diagram. Recently macro-micro region concept in the state diagram is proposed in order to handle the real challenges in combining different hurdles in food preservation. Finally the progress in microbial reaction, prediction models, molecular mobility, and guidelines from authorities are discussed in relation to the intelligent applications of hurdles. It was emphasized that further progress needs to be achieved in developing generic prediction models (boundary and dynamic) and fundamental understanding on the microbial responses to the hurdles in order to develop a classification of hurdles and their modes of attack.

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Nomenclature

a_w Water activity
D Decimal reduction time (s)
F_r Thermal death time at reference temperature (s)
F_o Thermal death time at reference temperature 121.1 °C (s)

G	Growth
k	Destruction rate (s^{-1})
N_o	Initial number of microorganisms
N_F	Final number of microorganisms
NG	No-growth
P	Probability
pH	Negative log hydrogen ion concentration
T	Temperature (°C)
T_c	Critical temperature (°C or K)
T_g	Glass transition temperature (°C)
t	Time (s)
X_b	BET-monolayer water content (g/g sample)
X_w	Water content (g/g sample)
z	Microbial thermal constant (°C)

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Chapter 3
Packaging Methods for Minimally Processed Foods

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3.1 Introduction

Consumers demand for minimally processed foods have significantly increased, primarily due to their interest in fresh and convenience foods, modern social trends, single person households, and willingness to spend money for quality products (Yang 1994; Singh et al. 2010). They constitute a full meal or a significant portion of it (fresh cut fruits, salads etc.), receive minimal processing treatments, often followed by refrigeration and freezing. A number of processing treatments applied to minimally processed foods do not ensure the 'sterility'. The operations of washing, sorting, peeling and cutting necessary to produce ready-to-eat products result in the reduction of the shelf life of the fresh-cut produce, with respect to the intact product, due to the accelerated enzymatic activity, moisture loss and microbial proliferation (Lucera et al. 2010). Especially fresh cut fruits and vegetables are subject to those deterioration processes (Conte et al. 2009). A large number studies have been conducted to prevent the detrimental phenomena occurring after cutting; most of them are based on treatments with reducing agents, acidifying agents, chelating substances and antimicrobial compounds (Lanciotti et al. 2004; Tripathi and Dubey

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2004; Rico et al. 2007). In particular control of the enzymatic browning in fresh-cut commodities, ascorbic acid and citric acid are widely used alone or in combination as substitutes for sulphite (Gimenez et al. 2003; Lee et al. 2003; Rocculi et al. 2004; Cocci et al. 2006; Albanese et al. 2007). Different calcium salts have also been studied for decay prevention, sanitation and nutritional enrichment of fresh fruits and vegetables (Martin-Diana et al. 2007). Fresh cut fruits and vegetables have a limited shelf life, due to mechanical stress, cell and membrane damage, water loss, enzyme activity, and microbial proliferation (Conte et al. 2009). The use of innovative non-thermal processing methods such as ultra-high pressure processing, pulsed electric fields, microwave sterilisation, ionizing radiations and active packaging helped to extend the shelf life and to increas the safety of minimally processed foods. Many factors influence the shelf life of fresh and convenience foods, and packaging is one of the key factors to keep the product fresh.

In a strict sense, it would be practically impossible for the food processors to distribute food without appropriate packaging, offering the well-known main packaging functions of containment, protection, convenience and communication (Robertson 2006; Wani et al. 2014a). A variety of packaging materials, each with unique properties and specific applications are in current use for packaging of foods. Detailed descriptions of packaging materials and their product specific use may be referred from the previous publication of Robertson (2006, 2012). The food packaging may be passive or active, the latter becoming the method of choice for fresh and convenience food categories. Passive packages are generally used for shelf stable food products, simply serving as a physical barrier between the product and the environment surrounding the package. Often, however, they are not appropriate for specific food products where the composition of the atmosphere in the package determines the quality and acceptability as in the case of minimally processed foods. Active packaging has been the focus of many studies in the last decade in many applications as in the case of the fresh and convenience food. A discussion on the properties of packaging materials in relation to the requirements from the side of the products would help readers to understand the criteria for the section of packaging materials.

3.2 Criteria for Selection of Packaging Materials

The selection of packaging material has a decisive effect on the quality and safety of minimally processed foods. Primary functions of commonly used packaging materials for food applications are listed in Table 3.1 may be used as standalone or in multi-layered form to meet the desired physical, mechanical and barrier properties. The important material properties such as mass transfer or barrier, optical, mechanical and migration aspects are discussed in the following sections.

Table 3.1 Primary functions of commonly used packaging materials for food applications

Packaging material	Abbreviation	Primary function
Aluminium	Al	High barrier
Glass	–	High barrier
Low density polyethylene	PE-LD	Sealing layers
High density polyethylene	PE-HD	Moisture barrier, rigidity, microwave capability, sealing layers
Oriented polyamide	OPA	Gas barrier
Amorphous polyester	APET	Rigidity, gas barrier
Crystallized polyethylene		
terephthalate	CPET	Rigidity, high temperature resistance, gas barrier
Ethylene-vinyl acetate	EVA	Sealing layers
Ethylene-vinyl alcohol	EVOH	Gas barrier
Oriented		
polyethylene-terephthalate	OPET	High temperature resistance, flexibility, puncture resistance, gas barrier
Oriented polypropylene	OPP	Moisture barrier, flexibility, puncture resistance
Polyamide (nylon)	PA	Temperature resistance, flexibility, toughness, partial gas barrier
Poly acrylonitrile	PAN	Gas barrier
Polyethylene terephthalate (polyester)	PET	Rigidity, some gas barrier
Polypropylene	PP	Moisture barrier, rigidity
Polystyrene	PS	Rigidity
Polyvinyl chloride	PVC	Rigidity, gas barrier
Polyvinylidene chloride	PVdC	Moisture barrier, gas barrier

3.2.1 Mass Transfer of Packaging Materials

Oxygen and water vapour permeability has significant importance for the maintenance of quality and safety for packed convenience foods. An illustration depicting the interactions of food, the package and the environment and the possible changes in food are shown in Fig. 3.1. Glass and metals are practically impermeable to gases and vapors, so these provide an efficient barrier against material exchange between the atmosphere inside the package and the outside environment. This virtually perfect barrier, desired for many durable food products, however, is often not needed or even negative for many of the products discussed below. polymers and paper are permeable to gases and vapors to various degrees, and their barrier properties certainly constitute the chief criterion in estimating their suitability to serve as packaging materials in a given application. Gases and vapors may pass through packaging materials either dissolved by solution-diffusion or by gaseous through holes and pores. Minimally processed foods, the main subject of this chapter, are diverse in nature and the requirements on the barrier are product specific. Fresh cut fruits and

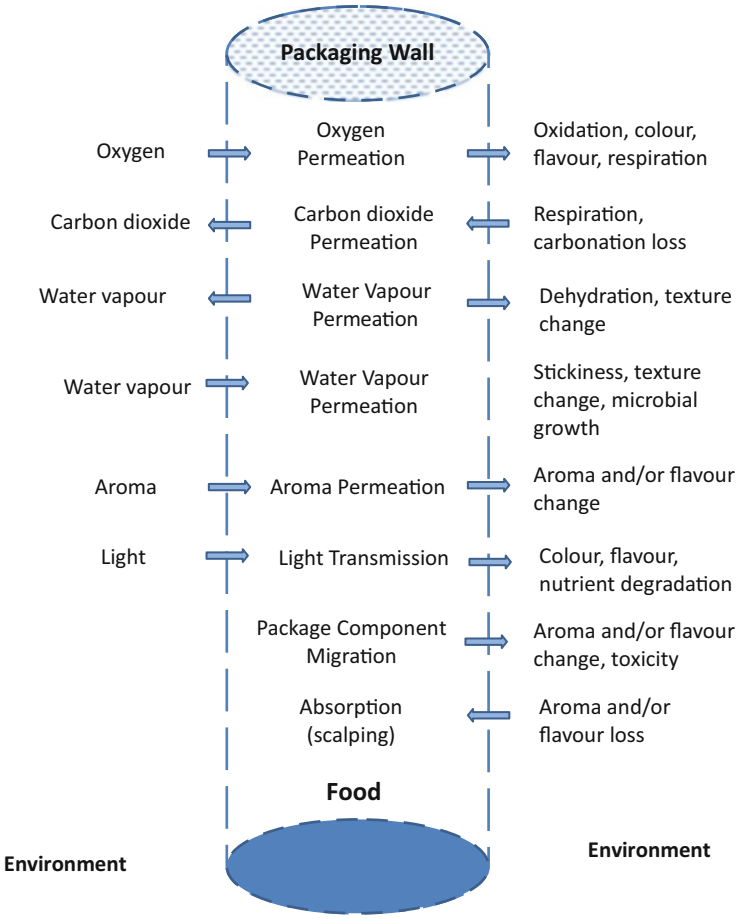

Fig. 3.1 Package, food, and environment interactions [Modified and adapted from Linssen and Roozen (1994)]

vegetables require packaging materials with a certain amount of water vapour permeability and an optimal level of oxygen, to avoid excessive condensation and anaerobic respiration. Meat based products may require higher levels of oxygen, in the case of fresh meat, or low levels, if the meat has already been processed, while the fresh cut salads again require high water vapour permeability to avoid in-package condensation.

3.2.2 Optical Properties

Optical properties of packaging materials are of practical importance; they affect the protective function of the package and partly influence the appearance and attractiveness. Transparency to light is particularly important in the case of glass

containers and polymer films. Many deteriorative reactions are catalyzed by light in general and ultraviolet light in particular. Light may influence lipid oxidation, off-flavor generation, discoloration, and degradation of nutritionally important components such as riboflavin, beta-carotene, ascorbic acid and certain amino acids (Bosset et al. 1994). On the other hand, transparent packages allow consumers to see the product through the package and judge on its quality by its appearance. This is important for products like fresh meat, poultry, fruits and vegetables, confectionery, baked goods and thermally preserved foods in glass jars (e.g., fruits in syrup, strained infant foods, etc.). A certain compromise between protection from light and transparency may be achieved by using coloured plastic or glass.

Plastic packaging materials may be opaque, hazy (translucid) or transparent. Plastic materials are rendered opaque by the incorporation of very fine solid particles of white or colored pigments into the melt. Haze or cloudiness is the result of light scattering (diffraction) by the crystalline micro-regions of the polymer. Amorphous plastics such as polycarbonate are clear (i.e. transparent). An inclusion of UV filter in the transparent packaging films has greatly reduced the above mentioned quality defects.

3.2.3 Mechanical Properties

The ability of a package to protect its contents against external forces depends on its mechanical properties. In packaging technology, mechanical properties should be considered and evaluated at the level of the packaging material, the formed empty package, the product package assembly and the outer packages. The mechanical strength of cans depends on the size, shape, thickness of the tinplate and geometric pattern of the can. At equal tinplate thickness, cans with smaller diameters are mechanically stronger. Frequently, the side walls of the can are beaded to increase mechanical strength. Except for the integrity and stability of the closure, mechanical strength is not an issue with glass. Relatively high output rates with minimal breakage can be achieved with adequately designed handling and conveying equipment, and with proper surface treatment to provide lubricity and prevent scratches. Peelability, seal strength, extensibility, tear strength etc. are some of the important mechanical properties for flexible packaging materials.

3.2.4 Migration from the Package

Migration, i.e. the transport of potentially harmful substances from packaging materials into the packed food products is a serious concern for the industry and consumers. Many factors influencing the migration of package components are: composition of the packaging material, material conversion and processing conditions and the food properties. The migration phenomena are now known for plastics and metal

packaging and are regulated worldwide for their acceptable limits. Examples of the migration of monomers or additives from polymeric packaging materials are vinyl chloride, acrylonitrile, styrene (as monomers), di- ethyl hexyl phthalate, acetyltributyl citrate (as plasticizers), among many other additives. For the single substances, maximum admissible values have been recommended by the relevant regulatory bodies on the basis of toxicological investigations. Predominantly seen as negative, this process may also create specific functions in active packaging when it comes to the dedicated release of substances.

3.3 Packaging Technologies for Minimally Processed Foods

Although a number of packaging technologies exist in the market, minimally processed foods have special packaging needs, since are believed to be close or similar to fresh products. Most conventional packaging systems like metal cans, glass bottles, and many flexible packagings, referred to as passive barriers, are limited to the physical barrier between the product and the environment. The passive packaging offers maximum protection to the product, but does not respond to the changes that might occur within the package and therefore may have limited use for the products under discussion. Packaging methods such as vacuum packaging, modified atmosphere packaging (MAP), active packaging methods, edible coatings, and microwave packaging are relevant to minimally processed foods and are discussed in this chapter.

3.3.1 Vacuum Packaging

Vacuum packaging is an old and widespread technique, applied to a variety of foods. Due to the removal of the atmosphere, especially oxygen from the headspace of the package, this technique may prevent oxidation reactions such as lipid oxidation, loss of certain vitamins, oxidative browning, loss of pigments, etc. Vacuum packaging also prevents deterioration by aerobic microorganisms and, particularly, moulds. Thus, fresh meat or minimally processed meat products packaged under vacuum may have a shelf life of a few weeks under refrigeration. Vacuum packaging offers additional advantages, such as reducing the volume and improving the rigidity of flexible packages. In retortable pouches, the vacuum helps to press the package against the food and thus improve heat transfer.

3.3.2 Modified Atmosphere Packaging

Modified atmosphere packaging (MAP), modifies the regular gas atmosphere (fractions by volume: 20.9 % O_2, 78 % N_2, and 0.03 % CO_2) inside the package to a different desirable composition of gases, leads to increase in shelf life and product

safety and thus helps to avoid food losses. Therefore, MAP is a viable solution for the shelf life extension of convenience or minimally processed foods. MAP offers additional benefits such as high product quality, waste reduction, reduced need for artificial preservatives and increased distribution possibilities (Wani et al. 2014b). MAP is generally used in combination with cold storage, to maintain the sensory and microbiological quality (González-Buesa et al. 2009). The huge diversity of food products demands specific MAP systems to meet the needs of the product.

It is important to understand the influence of each gas on food quality and shelf life. Carbon dioxide (CO_2) concentration ($\geq$20 %) is required to inhibit the growth of aerobic microorganism's. Excess levels of CO_2 inside the package can cause drip loss, flavor tainting and package collapse. Nitrogen (N2) as an inert gas is used to oxygen. Thus it helps to prevent oxidation and off flavor development At elevalted CO_2 iside the package, its function is to prevent package collapse, which caused by the absorption of CO_2 inside the package. Oxygen is generally reduced to a critical level in order to reduce, but still maintain the respiration of fresh cut fruits and fresh fruits, and to inhibit the spoilage caused by aerobic microorganisms. For fresh meat products, either elevated levels of oxygen may be used to transform the bearer of the red color, the myoglobin, into its cherry-red oxidised form oxymyoglobin or the oxygen level has to be reduced to maintain the initial state of the myoglobin. Intermediate oxygen levels have to be avoided as an irreversible transition into the grey metmyoglobin may occur.

Food grade gases or gas mixtures are available in the market for product specific MAP applications. Gas is generally supplied in single cylinders, micro bulk or as bulk supply. Single cylinders are used for small and medium volume users, and are available as pre-mixed or as single gases for individual use or onsite mixing. Micro bulk mode is a cost effective and reliable gas supply and may be used as small tank trucks and on site storage containers. For large scale commercial production, or those with high gas consumption, the storage of gas in bulk liquid is convenient and economical.

A wide range of packaging materials with desirable gas combinations for modified atmosphere packaging of minimally processed foods may be seen in Table 3.2. As described in Sect. 3.2, the choice of films used for MAP is determined by their water vapor and gas transmission rates. Polyester (PET), nylon (PA), polyvinylidene (PVdC) and ethylene vinyl alcohol copolymer (EVOH) are good gas barriers but have poor water vapour barrier properties. Polyethylene, polypropylene and ethylene vinyl acetate have very high gas transmission rates. Therefore, their use is reserved for cases where a high gas exchange rate with the environment is required to maintain the proper composition of MAP gases inside these packages. The oxygen/water vapour transmission rate for different packaging materials may be seen in Fig. 3.2. Typical films used for MAP lidding or packages for horizontal or vertical form- fill-seal machines are PET laminated to PE-LD, or PVdC coated PET laminated to PE-LD. Individual packaging films have limited gas and water vapour barrier properties. The option remains to co-extrude EVOH with LLDPE. Many additional options exist such as EVOH between PA 6 layers or without, usually in combination with PE-LD or PP. Preformed trays are often made from PET/PE or

Table 3.2 Recommended packaging materials, gas combinations and storage temperatures for some fresh and minimally processed foods

Packaging material	Packaging material		Gas mixture (by volume)	Gas: product ratio	Storage temperature	Typical shelf life	
	Bottom	Top				Air	MAP
Raw red meat	OPET/PE/EVOH/PE or XPP/EVOH/PE or EPS/EVOH/PE (XPP and EPS are expanded materials)	OPP/PE/EVOH/PE or OPET/PE/EVOH/PE or OPA/PE	60–80 % O_2 + 20–40 % CO_2	100–200 ml gas: 100 g meat	2–3 °C	2–4 days	5–8 days
Processed meat	OPET/PE/EVOH/PE or XPP/EVOH/PE or EPS/EVOH/PE or (XPP and EPS are expanded materials)	OPP/PE/EVOH/PE or OPET/PE/EVOH/PE or OPA/PE	30 % CO_2 + 10 % O_2 + 0–5 % N_2	50–100 ml: 100 g product	4–6 °C	2–4 days	2–5 weeks
Raw light poultry	OPET/PE/EVOH/PE or XPP/EVOH/PE or EPS/EVOH/PE (XPP and EPS are expanded materials)	OPP/PE/EVOH/PE or OPET/PE/EVOH/PE or OPA/PE	40–60 % CO_2 + 0–60 % N_2	100–200 ml: 100 g meat	2–3 °C	4–7days	16–21 days
Raw dark poultry	OPET/PE/EVOH/PE or XPP/EVOH/PE or EPS/EVOH/PE (XPP and EPS are expanded materials)	OPP/PE/EVOH/PE or OPET/PE/EVOH/PE or OPA/PE	70 % O_2 + 30 % CO_2	100–200 ml: 100 g meat	2–3 °C	4–7days	16–21 days
Fresh fish	OPET/PE/EVOH/PE XPP/EVOH/PE or EPS/EVOH/PE (XPP and EPS are expanded materials)	OPP/PE/EVOH/PE or OPET/PE/EVOH/PE or OPA/PE	40–90 % CO_2 + 10 % O_2 + 0–5 % N_2	200–300 ml: 100 g fish	0–2 °C	2–3 days	5–14 days
Sausages	PA/PE	PA/PE	20–30 % CO_2 + 70–80 % N_2	50–100 ml: 100 g sausages	4–6 °C	2–4 days	2–5 weeks
Fresh pasta	Metalised PET/PE	OPA/PE	30–60 % CO_2 + 40–70 % N_2	50–100 ml: 100 g product	2–4 °C	1–2 weeks	3–4 weeks
Fresh cut salads	OPP or PS/PE	OPA/PE	5 % O_2 + 5–20 % CO_2 + 75–70 % N_2	100–200 ml: 100 g product	3–5 °C	2–5 days	5–10 days
	PS/PE						
Fresh cut fruits	UPVC/ LDPE/-HD	OPP/OPP/PE/EVA/MP/MPOR	5 % O_2 + 10 % CO_2 + 85 % N_2	100–200 ml: 100 g product	0–3 °C	2–7 days	5–35 days

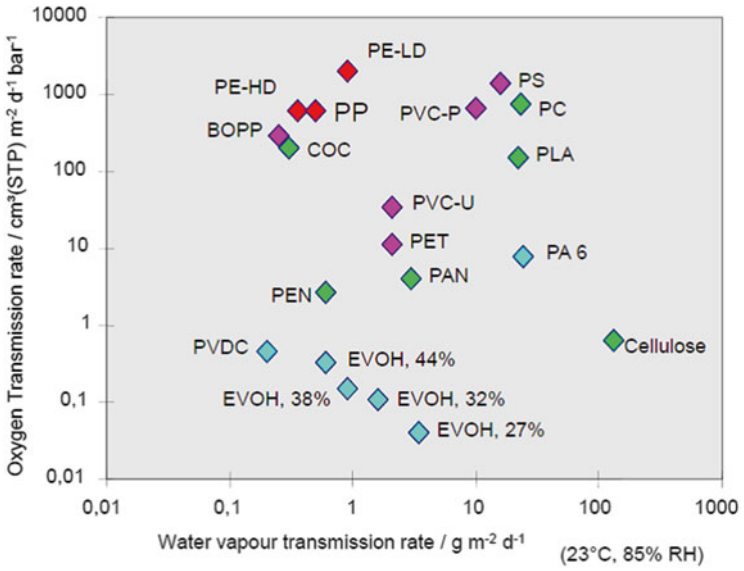

Fig. 3.2 Permeability of flexible polymers (100 µm) (Adapted with permission from Fraunhofer Institute for Process Engineering & Packaging IVV). *PE-LD* polyethylene low density, *PE-HD* polyethylene high density, *PS* polystyrene, *PC* polycarbonate, *PP* polypropylene, *BOPP* biaxial oriented Polypropylene, *COC* cycloolefine - copolymerm, *PLA* poly lactic acid, *PVC* polyvinylchloride, *PET* plyethylene terephthalate, *PA 6* polyamide 6, *PAN* polyacrylnitril, *PEN* polyethylene naphthalate, *PVDC* poly vinylidenchloride, EVOH—ethylenvinyl alcohol-copolymer; cellulose, regenerated cellulose (cellophane)

sometimes PET/PE laminates, wherein PE acts as a sealing layer, while the PET or PVC as the gas barrier and physical strength of the package.

Packaging formats without additional thermoforming like pouch, horizontal or vertical flow wrap are commonly used for MAP of convenience foods as well as thermoformed tray/lid combinations. For all packaging formats, it is important to know heat sealability of packaging materials to form hermetic conditions, and to prevent any leaks to ensure that the desirable gas mixture's retains within the package. PE-LD, PP, EVA are generally considered as perfect sealing layers to prevent any gas leakage. It is therefore important to know the compatibility between the sealing layers to ensure sealing integrity and the characteristic gas mixture. Seal integrity is often considered as critical control point to check the microbial contamination and air dilution of the contained gas mixture. Heat sealing, jaw or head alignment of sealing machines, dwell time, machine speed, temperature and pressure should be regularly checked to avoid any food safety and spoilage concerns.

3.3.3 Active Packaging

In recent years, active packaging has been the focus of food and packaging technologists, with the aim to increase the safety and quality of fresh and processed foods (Singh et al. 2011b). Moreover, the consumer's concern on the safety of foods containing synthetic chemical preservatives and the demand for minimally processed foods has led to the development of suitable active packaging techniques. Active packaging, sometimes known as interactive or intelligent packaging senses environmental change and alters the package to accommodate to the change (Brody 2005). Fernández-Álverz (2000) defined active food packaging as a heterogeneous concept with a wide range of possibilities to achieve shelf life extension and to facilitate processing and consumption of food. Active packaging is achieved by incorporating certain additives such as antimicrobial agents, antioxidants, ethylene scavengers, oxygen scavengers, humidity scavengers, off-flavour absorbers, ethanol emitters etc. An indicative list of active packaging systems is given in Table 3.3. Some of the active packaging technologies suitable for minimally processed foods are discussed in the following sections.

Table 3.3 Minimum growth conditions for selected microorganisms which may be associated with chilled MA packed foods

Type of microorganism	Minimum pH value for growth	Minimum aw for growth	Minimum growth temperature (°C)
Aeromonas hydrophila	4.0	< 0.96	0.0
Bacillus cereus	4.4	0.91	4.0
Clostridium botulinum (*proteolytic A, B and F*)	4.8	0.94	10.0
Clostridium botulinum (*non-proteolytic E*)	4.8	0.97	3.3
Clostridium botulinum (*non-proteolytic B and F*)	4.6	0.94	3.3
Clostridium perfringens	5.5	0.93	5.0
Enterobacter aerogenes	4.4	0.94	2.0
Escherichia coli	4.4	0.9	4.0
Lactobacilli	3.8	0.94	4.0
Listeria monocytogenes	4.4	0.92	–0.1
Micrococci	5.6	0.9	4.0
Moulds	<2.0	0.6	<0.0
Pseudomonas species	5.5	0.97	<0.0
Salmonella species	3.8	0.92	4.0
Staphylococcus aureus	4.0	0.83	7.7
Vibrio parahaemolyticus	4.8	0.94	5.0
Yeasts	1–5.0	0.8	–5.0
Yersinia enterocolitica	4.5	0.96	–1.3

3.3.3.1 Antimicrobial Packaging

Antimicrobial packaging, a promising active packaging concept is used to inhibit or kill spoilage and pathogenic microorganisms contaminating food. It has potential scope for minimally processed foods, as they receive only a minimal heat processing or other preservation treatment. Therefore, the antimicrobial packaging shall ensure the improvement in food safety and shelf life extension.

Approved antimicrobial compounds (i.e. natural or synthetic) for food use are incorporated into packaging materials, edible films, and coatings to inhibit microbial growth. However, packaging materials based on natural antimicrobial substances are gaining market because of their biological origin, perceived by consumers to be harmless. The antimicrobial based packaging systems follow two different principles: (1) the antimicrobial agent migrates from the package into the food, and (2) the antimicrobial agent is immobilised in the package (Corrales et al. 2014). The antimicrobial incorporation methods in practice are addition of sachets, dispersion in the packaging polymer, coating or dipping and antimicrobial macromolecules with film forming properties. The selection of antimicrobial agent for the right package and food shall ensure the release of the antimicrobial agents and inhibit or cease the microbial growth.

The antimicrobial compounds incorporated into the package may alter the mechanical and barrier properties of packaging materials. Some antimicrobial agents act as plasticizers, and improve the tensile properties, in particular the flexibility, of some polymers, such as in the case of polyvinyl alcohol (PVOH) modified with enterocin (Marcos et al. 2010). But, a decreased film strength has also been observed with increase in antimicrobial concentration in a packaging film (Pranoto et al. 2005). Changes in crystallinity can be attributed to the incorporation of antimicrobials in certain polymers (Bastarrachea et al. 2010), which certainly contribute to the modifications observed in the tensile properties. The barrier properties of the films are conditioned by the interfacial compatibility and hydrophobicity of the systems. Low interfacial compatibilities generate low adherence and voids in the material structure, as reflected in an increase in gas transmission rates (Robertson 2006). The partition coefficient of gases might also be altered due to the presence of new compounds in the polymer matrix. Gases will be more or less soluble to the package material due to the nature of the antimicrobial compound (Suppakul et al. 2003).

Biomaster®, AgIon®, Irgaguard®, Surfacine®, IonPure®, d2p®, Bactiblock® are some of the important antimicrobial silver-based master batches available in the market (Realini and Marcos 2014). Linpac Packaging Ltd. and Addmaster have developed a range of antimicrobial trays and lidding solutions containing Biomaster® silver-based additive to reduce the growth of foodborne pathogens such as *Salmonella*, *E. coli* and *Campylobacter* in fresh meat (LINPAC 2012). Similarly, Food-touch® from Microbeguard Corp. is an antimicrobial specialty paper containing Agion® silver based additive (Sciessent LLC) used as interleavers for fresh fish fillets during transportation in boxes (Agion 2007). Nanopack Technology and Packaging SL in collaboration with IRTA is developing a range of interleavers (Sanic films) able to extend the shelf life of vacuum packed meat

products (Nanopack 2014). Some companies offer other antimicrobial packaging solutions for meat products. SANICO® (Laboratories Standa) is a natamycine-based antifungal coating for sausages (Laboratories STANDA 2014b). Mitsubishi-Kagaku Foods Corp. has developed Wasaouro™ an antimicrobial material containing allyl isothiocyanate (Mitsubishi-Kagaku Foods Corporation 2002), a natural antibacterial and antifungal substance, and it is available in a variety of formats (sheets, labels and films).

3.3.3.2 Oxygen Scavengers/emitters

Most of the minimally processed foods are prone to oxygen mediated changes, leading to the off flavour development, nutritional loss and colour changes. These changes are undesirable and not only cause significant reduction in the quality and shelf life but also lead to rejection of food consignments leading to heavy economic losses to food industry. Although, the vacuum or MA packaging has been successful for oxygen removal, but the residual oxygen (0.3–3 %) in the headspace often leads to aerobic spoilage and off flavour development (Singh et al. 2011a). In most cases, removal of headspace oxygen from minimally processed and traditional foods has been the target for food industry to deliver fresh and safe food. Before we proceed further, we need to understand the reason for residual oxygen in the food. The residual oxygen may increase due to the oxygen permeability of the packaging material, poor sealing or leakage, air trapped in food, and inadequate gas flushing or evacuation. The oxygen induced deterioration in the minimally processed food may be minimized by oxygen absorbing systems that continuously reduce the residual oxygen inside the package. Theese oxygen scavengers are used in combination with MAP or vacuum packaging to remove the residual headspace oxygen for specific products (minimally processed meat, fish, fresh cheese etc.).

The existing oxygen scavenger technologies are based on iron powder oxidation, ascorbic acid oxidation, photosensitive dye oxidation, unsaturated fatty acids, and enzymatic oxidation or immobilized yeast on a solid substrate (Floros et al. 1997). The commercial sachets or pad based oxygen scavenging systems existing in the market are based on iron oxidation (Oxy-Guard™, Clariant Ltd.), oxygen absorption based cerium oxide particles (OxyCatch™, Kyodo Printing Company, Ltd.), and palladium metal and hydrogen gas-based oxygen absorber where palladium catalyzes the reaction between hydrogen and oxygen (FreshPax® (Multisorb Technolgoies, Inc.). The developments in the incorporation of oxygen scavengers, e.g. Cryovac® OS2000 (Sealed Air Corporation, USA), in the packaging material has not only increased the consumer perception but also reduced the risk of accidental rupture of the sachets and ingestion of their contents (Sealed Air 2013; Speer et al. 2009). OS2000 is a film with an integrated layer of an oxygen absorbing polymer from Chrvron Phillips which is triggered by UV irradiation. Bioka Ltd. Manufactures, PC Bebo Plastik GmbH, and Albis Plastic GmbH also offer oxygen scavenger films in various base materials such as PP, PE, EVA, & EVOH (AIPIA 2013; Albis 2014; Bioka 2014). The recent developments in incorporation

of oxygen scavengers allow their use for high temperature applications such as hot fill and retort (Mitsubishi Gas 2009a, b; AIPIA 2013).

3.3.3.3 CO_2/Emitters

Elevated levels of CO_2 are desirable for minimally processed meat, poultry, and fruits and vegetables products due to its antimicrobial action resulting in delay of lag phase, and generation time during microbial growth (Mexis and Kontominas 2014). This type of active packaging is frequently associated with modified atmosphere (MAP) systems in order to balance out CO_2 losses due to dissolution into the meat and permeation through the packaging material (Camo et al. 2008). An indicative list of CO_2 emitters is presented in Table 3.4. Kerry et al. (2006) reported that the drip losses from muscle foods are absorbed into pads and react with citric acid and sodium bicarbonate present in the pad resulting in the generation of carbon dioxide. Recently, Paper Pak Industries have launched UltraZap® XtendaPak pads, a more evolved version of CO_2 generators consisting of a mixture of citric and sorbic acids. It is designed as an absorbent pad for fresh meat, poultry and fish; and has a double antimicrobial effect due to the incorporation of a CO_2 emitter and an antimicrobial substance (Paper Pak Industries 2014). A Norwegian company reported the development of CO_2 emitter (SUPERFRESH) for fish fillets. The fillets are packed in MAP polystyrene box with a CO_2 emitter and upon absorption of fluids from the fillets it activates CO_2 emission. The advantages of this system is an increase in shelf life, no bulging or vacuum effect, reduced transport volume, and caused less environmental impact (Realini and Marcos 2014). The developments in CO_2 scavenger are increasing and the focus is on increasing the safety and cost reduction.

3.3.3.4 Humidity Regulated Packages

Moisture condensation inside the package for fresh produce, fresh cut fruits, salads, or drip loss in fresh meat often leads to product spoilage and its associated consumer health risk mainly due to physical and chemical changes, and an increase in the localized high water activity favours microbial growth. Therefore, the control of excess water inside the package has significant impact on the minimising the microbial growth and shelf life extension of packed food products. The most common moisture absorbing systems consist of a super absorbent polymer located between two layers of a micro-porous or non-woven polymer. This material is supplied as sheets of various sizes that are used as drip-absorbing pads typically found in tray formatted (overwrap and modified atmosphere) fresh muscle food products (Kerry et al. 2006). This is generally achieved by directly placing the moisture absorbing pads inside the package or incorporating the moisture absorbers in the films. Sängerlaub et al. (2011) investigated the salt incorporation inside the packaging trays to control the moisture condensation for several minimally processed foods.

Table 3.4 Types of active packaging and commercial applications applied to muscle foods (Ciolacu et al. 2014; Adapted with permission from Elsevier Science UK)

Active packaging		
Commercial name	Supplier	System
Moisture absorbers		
Dri-Loc®	Sealed Air Corporation	Absorbent pads
MoistCatch	Kyodo Printing Co., Ltd.	
MeatGuard	McAirland Inc.	
Linpac	Linpac Packaging Ltd.	Absorbent trays
Fresh-R-Pax®	Maxwell Chase Technologies	
TenderPac®	SEALPAC	Dual-compartment system
Nor® Absorbit	Nordenia International AG	Flexible microwavable system
Antimicrobial packaging		
Biomaster®	Addmaster Limited	Silver-based masterbatches
Aglon®	Life Materials Technology Limited	
Irgaguard®	BASF	
Surfacine®	Surfacine Development Company LLC	
IonPure®	Solid Spot LLC	
d_2p®	Symphony Environment Ltd	
Bactiblock®	NanoBioMatters	
Biomaster®	Linpac Packaging Ltd	Silver-based trays and films
Food-touch®	Microbeguard Corp.	Interleavers
Sanic Films	Nanopack	Interleavers
SANICO®	Laboratories Standa	Antifungal coatings
Wasaouro™	Mitsubishi-Kagaku Foods Corp.	Antibacterial and antifungal sheets, labels and films
Carbon dioxide emitters		
CO_2®Fresh Pads	CO_2 Technologies	CO_2 emitter pads
UltraZap® Xtenda Pak pads	Paper Pak Industries	CO_2 emitter and antimicrobial pads
SUPERFRESH	Vartdal Plastindustri AS	Box system with CO_2 emitter
Oxygen scavengers		
OxyGuard™	Clariant Ltd	Sachets
OxyCatch™	Kyodo Printing Company Ltd	
FreshPax®	Multisorb Technologies, Inc.	
ATCO®	Laboratories Standa	Labels
Ageless®	Mitsubishi Gas Chemical Inc.	
Cryovac ®OS2000	Sealed Air Corporation, USA	Films
Enzyme-based	Bioka Ltd	
Shelfplus®	RPC Bebo Plastik GmbH	Masterbatch used in high barrier containers
OxyRx™	Mullinix Packages Inc.	Containers and films suitable for high temperature
OMAC®	Mitsubishi Gas Chemical Inc.	

Commercial available moisture absorbing pads such as Cryovac®Dri-Loc® (Sealed Air Corporation), MoistCatc™ (Kyodo Printing Co., Ltd.), and MeatGuard® (McAirlaid Inc.) are generally incorporated inside the high water barrier packages. The new developments in moisture absorbing systems consist of multilayer packaging materials that include an absorbing layer between the packaging layers. The use of moisture regulating films is approved by the FDA and EU food contact regulations. Many companies are marketing moisture regulating films under brand names TenderPac®, and Nor®Absorbit. Nor®Absorbit (Nordenia International AG) are some additional examples of a moisture absorbing flexible microwavable packaging material. During microwave cooking, the Nor®Absorbit films are able to absorb excess grease and water released by packed foods.

3.3.3.5 Ethylene Scavenging

Ethylene, a plant growth hormone, induces ripening in the climacteric fruits and tells the shelf life of fresh plant produce. Once the fruits are ripe, ethylene may cause increase in respiration rates leading to undesirable attributes such as textural loss and colour changes. Therefore, ethylene scavenging is practiced for many years to reduce the ripening of fruits before they are sent for retail markets. Among the ethylene scavengers available in the market, potassium permanganate embedded in silica is inexpensive the most commonly used ethylene scavenger. The silica absorbs ethylene, and potassium permanganate oxidizes it to ethylene glycol. Silica is kept in a sachet, highly permeable to ethylene, or it can be incorporated into the packaging film. There are also a number of ethylene scavengers using some form of activated carbon or zeolite with various metal catalysts. The direct surface contact between the ethylene scavenger and the fruit should be avoided due the toxicity of potassium permanganate. Activated carbon or zeolite with various metal catalysts are also reportedly used as ethylene scavengers (Mexis and Kontominas 2014). They are generally placed in paper bags or sachets inside the store rooms or for retail purpose. Ethylene scavengers are quite effective in extending the storage of packaged fruit, including kiwifruit, bananas, avocados, persimmons, and vegetables like carrots, potatoes, and Brussels sprouts.

3.3.3.6 Ultraviolet Light Filters

The consumers' interest in transparent packaging, may often lead to the development of off flavours, degradation of omega fatty acids, PUFA's, carotenoids, vitamins, and other nutrients. The above listed changes are initiated or accelerated by sunlight and especially ultraviolet (UV) light, which causes degradation of specific food constituents via a photo catalytic auto degradation. It is therefore important to add a UV barrier e.g. Nylon 6 of modified crystallinity, in the transparent packaging films of polyolefin. The incorporation of UV filters is very essential for retaining the colour of meat sausages displayed in retail light cabinets, milk based products, fruit pastes, oils etc.

3.3.4 Edible Films and Coatings

Edible films and coatings offer an excellent solution for the shelf-life extension of fresh and minimally processed fruits and vegetable products. The edible films and coatings have advantages over other packaging materials, mainly due to zero waste or reduction in packaging material which contributes to limit pollution and environmental damage. Additionally, they offer solutions for moisture barrier, gases and microorganisms besides improving the mechanical resistance of packed foodstuff. Edible coatings are composed of a variety of substances mainly biopolymers and edible additives. They can be grouped into carbohydrates, proteins and lipids, which have different characteristics to produce the desirable coating or film to meet the product specific needs (Table 3.5). Most of the edible films and coatings are fabricated by blending the polysaccharides, proteins and/or lipids to improve their permeability or mechanical properties based on product specific applications. These differences in films can be achieved using various methods, either in the form of an emulsion, suspension or dispersion of the non-miscible constituents, or in successive layers (multilayer coating or films), or in the form of a solution in a common solvent. The method of application affects the barrier properties of the films obtained (Khin et al. 2005).

Although the edible films and coatings have many food applications, they are mainly used to decrease the water vapour transmission rate to preserve the texture loss in fruit, vegetables, fresh cut salads or fruits etc. (Chien et al. 2007; Olivas et al. 2007; Dhanpal et al. 2012); to reduce respiration rates and an increase the shelf-life (Kays and Paull 2004); to control browning; and to preserve freshness and flavour (Olivas et al. 2007). The important considerations while developing the coatings are the adhesion properties specific to the product where it is intended to be used. Dipping is the most common method for applying coatings on the fruits and vegetables, while brushing, spraying, solvent casting and extrusion are also used on food products and for film requirements on the food surfaces. Several functional additives including antimicrobial agents are incorporated in the edible films and coatings for the prevention of spoilage and pathogenic bacteria. Organic acids and plant essential oils are used as antimicrobial agents for the coatings of in fresh cut fruits and vegetables (Du et al. 2009). EU regulation 1331/2008 permits the use of natural antimicrobials to the extent to achieve a desirable effect or unless they are harmless. US FDA regulations permit the use of edible coatings as they are generally recommended as safe (GRAS) and the additive applied should be in accordance with good manufacturing practices. However, the use of ingredients which may be allergenic e.g. milk ingredients, soy or peanut proteins should be labelled to avoid allergenic reactions to the consumers.

3.3.5 Microwaveable Packaging

The microwave oven heating demands the microwavable packaging of processed foods. Microwave active packaging has potential use in minimally processed foods, which includes the use of susceptors, reflectors, guidance systems, microwave

Table 3.5 Commercial available edible coatings (Ciolacu et al. 2014; Adapted with permission from Elsevier Science UK.)

Name	Company	Composition	Fruits/vegetables
Fresh Seal™	BASF Corporation, NJ; USA	Cellulose derivatives and emulsifiers	Avocado, cantaloupe, mangoes, papaya
Natural Shine™	Pace International, LLC, USA	Carnauba wax	Citrus
NatureSeal ™Agricoat	Mantrose-Haeuser Co., Inc., USA	Cellulose derivatives without sucrose fatty acid esters	Most fruits and vegetables
PacRite®	Pace International, LLC, USA	Water-based, carnauba-shellac emulsions, shellac and resin water emulsion, water-based mineral oil fatty acid emulsions	Citrus, stone fruits, vegetables, potatoes
PrimaFresh®	Pace International, LLC, USA	Mineral-oil base	Cherries, stone fruits, mangoes, melons, apples
Schield-Brite products	Pace International, LLC, USA	Shellac/carnauba-based, natural wax vegetable oil/ wax and xanthan gum	Citrus, pears, stone fruits
Semperfresh™	Mantrose Ltd, UK	Sucrose esters of fatty acids, sodium carboxymethyl cellulose	Most fruits and vegetables, nectarines
TAL Pro-Long (Pro-Long)	Courtaulds Group, UK	Sucrose polyesters of fatty acids and the sodium salt of carboxymethyl cellulose	Pears, apples, bananas, plums

'doneness' indicators and 'smart adhesives' used during the form/fill/seal machines (Yang 1994; Regier 2014). The active microwavable packaging strongly changes the microwave field compared to what it would be without the packaging; that is, such packaging is designed to ameliorate the heating behaviour of the food. Glass coated microwave film, retort pouches with peel able aluminium foil, shield packaging with open structures, elevated susceptor package for pizza baking are some of the commercial examples for active microwave packaging.

3.3.6 Migration Aspects

The migration of low molecular weight substances from packaging materials to food has been investigated intensively. The substances of interest are monomers and processing additives used in production of the plastic material. The migration of vinyl chloride monomer from packages made of PVC (polyvinyl chloride) has increased the safety concerns and associated health risks, because this monomer (VCM) is a potent carcinogen. Another monomer, whose presence in food is objectionable, is acrylonitrile monomer. Processing additives that may migrate to the food are mainly plasticizers, antioxidants and solvent residues. While the

polymer industry has invested considerable efforts to overcome the problem by technological means, research has developed increasingly sensitive methods for the detection of the contaminants. The toxicology of the substances in question is known, and regulations covering the issue are available in most countries.

The diffusion of antimicrobial compounds through packaging materials depends on physical and chemical factors. Interactions with the packaging polymer through hydrogen bonds, hydrophobic or electrostatic interactions, etc., are highly important, but also the presence of additives, such as nanoclays, might decrease diffusion rates due to tortuosity (Picard et al. 2008). The diffusion coefficients of antimicrobials are generally lower in packaging polymers than in food matrices (Bastarrachea et al. 2011); consequently, small amounts of antimicrobials could be transferred to the food and the amount could be kept above the minimum inhibitory concentration.

Antimicrobials can diffuse across a gradient up to saturation, when the release slows or stops. In other cases, an antimicrobial is released at once and the effect ceases when the antimicrobial is consumed (Han 2005). In the best-case scenario, in polymers that are not affected by the food system, antimicrobials diffuse following Fickian diffusion laws. Moisture, pH, and water activity (aw) of the food affects the diffusion rates of the antimicrobial from the package into the food matrix. For instance, the incorporation of soluble potassium sorbate into packaging materials (e.g., plastic films or papers) to extend the shelf life of high moisture foods; such as paste, yogurt, fruit jelly, soft cheese, and sliced ham; did not exert the expected antimicrobial effect. Potassium sorbate immediately diffused on the food surface, coeluting with food compounds which tempered its antibacterial properties. The pH affects the growth rate of microorganisms and changes the degree of ionization (dissociation/association) of active chemicals (Han 2005). The permeation of sorbic acid decreased when the pH increased from 3 to 5 (Rico-Pena and Torres 1991). Similarly, Weng and Hotchkiss (1993) found that benzoic anhydride low-density polyethylene (PE-LD) was more effective at a low pH. In another study, nisin incorporated into cellulose-based films did not inhibit *Listeria monocytogenes* in peptone water. This has been attributed to a possible neutralization of the bacteriocin by pH (Grower et al. 2004). The water activity (aw) is another decisive parameter in the antibacterial efficacy of a package. A high aw allows higher permeation of the antimicrobial into the food as compared to low aw. This can reduce the amount available for protection (Vojdani and Torres 1989; Wong et al. 1996). The release of an antimicrobial can also be controlled by environmental conditions. In particular, temperature can accelerate the release of the antimicrobials into foods which in turn enhance their antimicrobial properties (Vojdani and Torres 1990; Wong et al. 1996). This does not apply to temperature-sensitive compounds, whose antimicrobial properties can be depleted by the effect of temperature (Weng and Hotchkiss 1993).

3.4 Conclusions

There are numerous minimally processed food products available in the market, and their number is growing at an increasing rate. The packaging requirements for minimally processed need controlled permeability with additional features to keep the food fresh and safe throughout its shelf life. The developments in MAP and active packaging have increased the shelf life and safety of convenience food products. New research efforts to produce cost effective and stable active packaging systems will further increase in the global market and will provide safety of fresh and convenience foods.

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Chapter 4
Washing, Peeling and Cutting of Fresh-Cut Fruits and Vegetables

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4.1 Introduction

The consumptions of fresh fruits and vegetables are directly linked to reduced risk of chronic diseases and to enhance resistance against diseases (Van Duyn and Pivonka 2000). In addition to the pleasure of eating fruits and vegetables, these provide various phytochemicals and antioxidants (Kalt 2005), phytoestrogens, and anti-inflammatory agents (Vincent et al. 2010) and other protective compounds (Kaur and Kapoor 2001; Slavin and Lloyd 2012). These aspects of health benefits led to the tremendous increased market for fresh cut and minimally processed fruits and vegetables. Fresh-cut products are preferred over processed one because consumers are now aware of the commonly nutritional losses, desired sensory attributes such as color and flavor and increased demand for 'natural-like' attributes (Kader 2002). The fruits and vegetables constitute a suitable meal for satisfying today's lifestyles, because these need minimal preparation and provide a great meals with varieties of nutrients, vitamins and minerals (Froder et al. 2007).

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One of the major problems of the fresh-cut industry are the high perishability of fruits and vegetables, for examples susceptible to tissue softening, wilting, spoilage and cut surface browning (Soliva-Fortuny and Martín-Belloso 2003) and microbial spoilage (Harris et al. 2003). These changes are enhanced by the processing steps such as washing, peeling, and cutting. However a good quality of fresh-cut produce can be maintained if pre-processing (i.e. cultivar variety, cultivation practices, harvesting, and ripening stage), processing (i.e. precooling, cleaning, cutting, peeling, coring, handling, washing, disinfecting, rinsing, packaging) and distribution (i.e. temperature, relative humidity, atmosphere composition and duration) conditions are maintained optimally.

4.1.1 Factors Affecting Quality of Fruits and Vegetables

The fruits and vegetables are subjected to physical, chemical, and microbiological stresses during harvesting, distribution, processing, packaging and storage (Hodges and Toivonen 2008). Fresh cut fruits and vegetables are composed of cells that naturally deteriorate over time and are affected by preparation, post-harvest conditions, processing, and storage time (Montero-Calderón and Cerdas-Araya 2009). The spoilage of fresh-cut fruits and vegetables can be identify by two ways, one is the physiological damage due to metabolic and enzymatic activity of the tissue of the plants, and the other one is the microbiological spoilage due to microbial growth (Regaert et al. 2009). During peeling and processing operations of fruits and vegetables, many cells are destroyed and their components serve as a source of nutrients for the growth of bacteria, fungi and yeasts (Erturk and Picha 2006). Biochemical changes, such as enzymatic browning also cause deterioration and quality losses (Watada and Qi 1999).

Another concern for the fresh-cut industry is the presence of pathogenic bacteria in their final product. This represents a food safety risk. Fruits and vegetables particularly leafy greens (i.e. salad) are consumed raw and these are being recognized as important vehicles for transmission of pathogens (Berger et al. 2010; Harris et al. 2003). Severe outbreaks have been reported in the case of contaminated radish sprouts and pre-packaged spinach. Nguyen-the and Carlin (1994) reported that microbial populations can range from 10^2 to 10^9 CFU/g on in fruits and vegetables. Gram-negative bacteria dominate the microflora associated with most vegetables, whereas yeasts and moulds are often the majority microflora with fruits (Burnett and Beuchat 2000; Tournas and Katsoudas 2005). As a consequence of the increasing number of outbreaks of food-borne illness, greater attention has been given to intervene in killing or removing pathogens contaminated in the fresh produces (Sapers 2001).

Many processing innovations and automations are being implemented to improve different processing stages, such as washing, peeling, cutting, packaging, and storage. Lehto et al. (2011) stressed on the maintaining of hygienic level by minimizing

cross-contamination in fresh-cut fruits and vegetables. This chapter stresses on processing steps, such as washing, peeling and cutting in order to extend shelf-life of fresh-cut fruits and vegetables.

4.2 Washing

Fruits and vegetables often contain a great diversity of microflora and are frequently involved in food-borne outbreaks. Since fruits and vegetables are mainly consumed uncooked or minimally-processed (such as in ready-to-eat salads), microbiological safety becomes an important issue to minimize consumers risks (Sagoo et al. 2003). Recently, a number of outbreaks have been traced to fresh-cut fruits and vegetables, which were caused due to inadequate sanitary conditions. The investigations of these outbreaks showed that the quality of water used for washing was crucial (CDC 2009). It is well known that disinfection is one of the most critical processing steps in fresh-cut fruits and vegetable production (Gil et al. 2009). This step commonly affects the quality, safety and shelf-life of the end product. Washing is designed to remove dirt, selected pesticides and to detach microorganisms to enhance quality (Zagory 1999). Sanitization is the killing of contaminated microorganisms after washing.

Chemical methods of cleaning and sanitizing involve the application of mechanical washing in the presence of sanitizers (Artés and Allende 2005). Sanitizers can reduce the growth of natural microbial populations on the surface of fresh-cut produce by 2–3 log units and can reduce contaminated pathogens (Gonzalez et al. 2004; Selma et al. 2008b).

4.2.1 Washing Sanitizers and Washing Aids

It is well known that water serves as a source of cross contamination as it is re-used. The water used for washing may result in the building of microbial loads if it is not properly managed. The importance of water quality used for washing need to be applied and sanitizing agents could be used to maintain the quality of the water. This can prevent cross contamination and microbial spoilage of the final product. In general, it could be assumed that the cleaning action of the washing removes microorganisms by detaching them from the products and sanitizing agent eliminates them by killing (Gil et al. 2009).

Ideal sanitizing agent should have two important properties: a sufficient level of antimicrobial activity and a negligible effect on the sensory quality (Allende et al. 2008). A range of disinfectant and sanitizers are described in the next sections. These are chlorine, chlorine dioxide (ClO_2), organic acids, ozone, hydrogen peroxide, electrolyzed water and trisodium phosphate (TSP).

4.2.2 Chlorine

Gaseous chlorine and its derivatives (sodium and calcium hypochlorite) have been used for sanitation purposes in food processing for several decades (Cherry 1999). The population reduction on produce surfaces are within the range of 1–2 log units if it is used at permitted concentration. The antimicrobial effect of chlorine is attributed to the breaking of chemical bonds in molecules such as enzymes and proteins (Chung et al. 2011). Chlorine also combines with cell membrane proteins to form N-chloro compounds, which interfere with cell metabolism (Beuchat 1992). Following reactions occur when gaseous chlorine or hypochlorites are added to water:

Cl_2	+	H_2O	⟶	HOCl	$+H^+$	+	Cl^-
NaOCl	+	H_2O	⟶	NaOH+	HOCl		
$Ca(OCl)_2$			⟶	Ca^{2+}+	$2OCl^-$		
$Ca(OCl)_2$	+	$2H_2O$	⟶	Ca(OH)2	+2HOCl		
HOCl			⟶	H^++	OCl^-		

The use of chlorinated water as a decontamination stage in the washing of fresh-cut produce is widespread throughout the fresh produce industry. The concentrations vary from 50 to 200 ppm and typical contact times of less than 5 min are used (Rico et al. 2007). The effect of chlorine concentration on aerobic microorganisms and fecal coliforms was studied (Velázquez et al. 2009). The exposure of lettuce and tomatoes to 100–2,000 ppm of chlorine has been shown to decrease microbial populations by approximately 2–4 log. Rodgers et al. (2004) reported that at 200 ppm chlorine after 5 min exposure reduced *E. coli* O157:H7 and *L. monocytogenes* to undetectable levels on apples, lettuce, strawberries and whole melons. In their study, the best reduction was observed as 4.77 log reduction for *Y. enterocolitica* in the case of tomatoes. On the other hand, total aerobic mesophilic population of uncut peeled carrots was reduced by 2.3 log CFU/g after application of 200 mg/L of chlorinated water at 50 °C (Klaiber et al. 2005). The application of chlorine at 50 ppm of chlorine in iceberg lettuce reduced the *E. coli* O157:H7 populations by 3.79 log CFU/mL after 90 s of treatment (Davidson et al. 2013). Similarly, Posada-Izquierdo et al. (2013) reported that chlorination treatment followed by a rinsing step in tap water reduced the initial level of *E. coli* O157:H7 by 1.23 log CFU/g. The populations of *Shigellasonnei* inoculated onto whole parsley leaves were reduced by more than 7 log CFU/g after treatment for 5 min with 250 ppm of free chlorine (Van Duyn and Pivonka 2000).

Although the potential of chlorine to inhibit microorganisms has been reported, its interaction with some components, such as organic matter leads to the formation of carcinogenic halogenated disinfection by-products like trihalomethanes (THMs) and haloacetic acids (HAAs) (Gil et al. 2009). Safety concerns of these compounds and their impact on human and environmental raise to explore alternatives of chlorine.

4.2.3 Chlorine Dioxide

The major advantages of chlorine dioxide (ClO_2) over chlorine and HOCl are their reduced reactivity with organic matter and greater activity at neutral pH. The oxidation capacity of chlorine dioxide is about 2.5 times greater than chlorine (Parish et al. 2003). It can be produced via two different reactions: reacting an acid with sodium chlorite, or reacting sodium chlorite with chlorine gas (Mari et al. 2003). A maximum of 200 ppm of ClO_2 is allowed for sanitizing of processing equipment and 3 ppm maximum is allowable for contact with whole produce (Parish et al. 2003). It has been reported that chlorine dioxide at 10 ppm for 10 min was found to be effective in the reduction of *Escherichia coli* O157:H7 by 1.48–1.97 log CFU/g on shredded lettuce and baby carrots (Singh et al. 2002). Minimally processed lettuce and cabbage immersed in a cysteine solution followed by treating with ClO_2 prolonged their shelf-life. The gas treatment significantly reduced the initial aerobic, psychrotroph, yeast counts and pH of the cabbage (Gómez-López et al. 2008). On the other hand, the sanitizing effects of ClO_2 solutions against *Salmonella* Enterica and *Erwinia carotovora* in tomato surfaces have been reported by Pao et al. (2007). These authors reported that ClO_2 at 20 and 10 ppm reduced 5 log CFU/g of *S*. Enterica and *E. carotovora* counts. The only disadvantage is the instability of ClO_2, it must be generated on-site and can be explosive when concentrated.

4.2.4 Organic Acids

Organic acids such as acetic, benzoic, citric, malic, sorbic, succinic and tartaric are naturally found in a variety of fruits and fermented foods (Sapers 2009). They are known to have bactericidal activity and they are generally recognized as safe (i.e. GRAS) (Dickson 1992). The antimicrobial action of organic acids is due to pH reduction in the environment, disruption of membrane permeability, anion accumulation, or a reduction in internal cellular pH by the dissociation of hydrogen ions from the acid (Beuchat 2000). For this reason, some investigation has been focused in the application of these compounds to preserve and extent the shelf life of fresh and fresh-cut fruits and vegetables.

Numerous studies have demonstrated the efficacy of organic acids to decontaminate fresh-cut vegetables. Karapinar and Gönül (1992) evaluated the use of acetic acid to inactivate *Yersiniaenterocolitica* on fresh parsley. The results showed a reduction of more than 7 log cycles after washing for 15 min in solutions of 2 % acetic acid or 40 % vinegar. In addition, treatment in 5 % acetic acid for 30 min did not result in any recovery of aerobic bacteria, while treatment with vinegar gave a 3–6 log decrease in aerobic counts. The inactivation depended upon vinegar concentration and contact time (Karapinar and Gönül 1992).

In the case of mixed salad vegetables treated with 1 % of lactic acid, coliforms and fecal coliforms were reduced about 2 and 1 log CFU/g, respectively, (Torriani

et al. 1997). Also, lactic acid at 2 % for 15 s was used to reduce *Aeromonas caviae* on minimally processed carrot by 2.54 log CFU/mL (Uyttendaele et al. 2004). Moreover, the application of mixture of organic acids (malic, lactic and citric) at 2 % in combination with ultrasound for 5 min showed a reduction of *E. coli* O157:H7, *S.* Typhimurium, and *L. monocytogenes* by 2.75, 3.18, and 2.87 log CFU/g, respectively, in fresh lettuce leaves. In addition, color and texture parameters did not affect (Sagong et al. 2011). These studies demonstrated the capability of organic acids to reduce and inhibit pathogenic bacteria in fresh-cut fruits and vegetables.

4.2.5 Ozone

Ozone as an aqueous disinfectant was declared to be generally recognized as safe (GRAS) (Guzel-Seydim et al. 2004). Ozone has been more effective to inhibit bacteria, viruses, and fungal spores than hypochlorite (Khadre et al. 2001). The lethal effect of ozone is a consequence of its strong oxidizing power (Seymour 2003). Microbial studies in laboratory testing typically show a 2 log reduction in total microbial counts and significant reduction of spoiling microorganisms commonly found in fruits and vegetables (Khadre et al. 2001). Ozone has been found to be effective against *S.* Typhimurium, *Y. enterocolitica*, *S. aureus*, and *L. monocytogenes* at 20 ppm (Xu and Wu 2014). Kim et al. (1999) reported a 2 log CFU/g reduction in total counts for shredded lettuce suspended in water ozonized with 1.3 mM ozone as compared to water washing (0.74–1.0 log cfu/g reduction). In addition, ozone at 5 ppm were able to inactivate *E. coli* with a 2.2 log reduction in tomato after 15 min of exposure (Bermúdez-Aguirre and Barbosa-Cánovas 2013).

It has been reported that efficacy of ozone treatments can be improved by extending the exposure time. Xu and Wu (2014) evaluated the efficacy of ozonized water (6.25 ppm) at 3 levels of exposure times (1, 5 or 10 min) in green onions inoculated with S*almonella* spp. Their results showed that reduction of *Salmonella* spp. increased from 1.90 to 3.10 log with the increasing time from 1 to 10 min. Ozone treatment in combination with UV-C illumination (UV) reduced microbial flora of fresh-cut onion, escarole, carrot, and spinach wash waters by 6.6 (O_3-UV), 4.0 (UV) and 5.9 log CFU/ml (O_3), respectively (Selma et al. 2008a, b).

4.2.6 Hydrogen Peroxide

Hydrogen peroxide (H_2O_2) is a compound Generally Recognized as Safe (GRAS) and possesses bactericidal and inhibitory activity due to its oxidative properties and their capacity to generate other cytotoxic oxidizing species such as hydroxyl radicals (Ayala-Zavala and Gonzalez-Aguilar 2011). The use of H_2O_2 has been reported

by Ukuku et al. (2004). These authors reported that the immersion of fresh-cut cantaloupe melon in H_2O_2 solution (5 %) caused a 4.6 log CFU/cm^2 reduction of *Salmonella* spp. Similarly, inoculated apples and cantaloupes showed that the same concentration of H_2O_2 solutions can achieve 3 log CFU/g reduction at 20 °C (Sapers et al. 2001). Combinations of 5 % of H_2O_2 with acidic surfactants at 50 °C produced a 3–4 log reduction of nonpathogenic *E. coli* inoculated onto the surfaces of unwaxed Golden Delicious apples (Sapers et al. 1999).

4.2.7 Electrolysed Water

Electrolyzed water (EW) has a strong bactericidal effect against pathogens and spoilage microorganisms. This is more effective than chlorine due to its pH, high oxidation reduction potential (ORP) and the presence of residual chlorine (Bari et al. 2003; Kiura et al. 2002). This is produced by the electrolysis of ordinary tap water with sodium chloride in an electrolysis chamber to form acidic and alkaline EW (Fig. 4.1). Some studies showed that acidic EW solutions inhibit the growth of food pathogens in some fruits and vegetables such as strawberries (Koseki et al. 2004a, b), fresh-cut cabbage (Achiwa et al. 2003), and tomatoes (Bari et al. 2003).

Acidic EW showed inhibitory effect against *E coli* O157:H7 by reducing their counts to 4.45 log CFU/g when green onions were treated for 1 min (Park et al. 2008). They compared their results with distillated water treatment. Koseki et al. 2004a, b evaluated the effect of washing with alkaline EW followed by acidic EW in cut lettuce against *E. coli* O157:H7 and *Salmonella* spp and they observed a reduction of microbial populations by approximate 1.8 log CFU/g (Table 4.1).

4.2.8 Trisodium Phosphate

Trisodium phosphate (Na_3PO_4) is highly soluble in water and it produces an alkaline solution. The antimicrobial activity of TSP probably is due to its high pH (pH 12) which disrupts the cytoplasmic membrane (Sampathkumar et al. 2003). Zhuang and Beuchat (1996) studied the effectiveness of TSP treatment on the inactivation of *Salmonella* Montevideo on tomatoes. They found that dipping tomatoes in a solution at 80 and 120 mg/mL for 15 s reduced the microbial population by 2.46 and 3.46 log CFU/ml, respectively. On the other hand, Kamber et al. (2010) evaluated the effect of 1 % of TSP on *Salmonella enteritidis* and the results showed more than 5 log CFU/mL reduction in the cases of both species after 15 min. It is well known that the washing step in preparing fresh-cut fruits and vegetables is vital for maintaining the quality of the end product. However, peeling and cutting can also damage the tissues of fresh fruits and vegetables. This could cause susceptible to microbial growth, and leakage of nutrients.

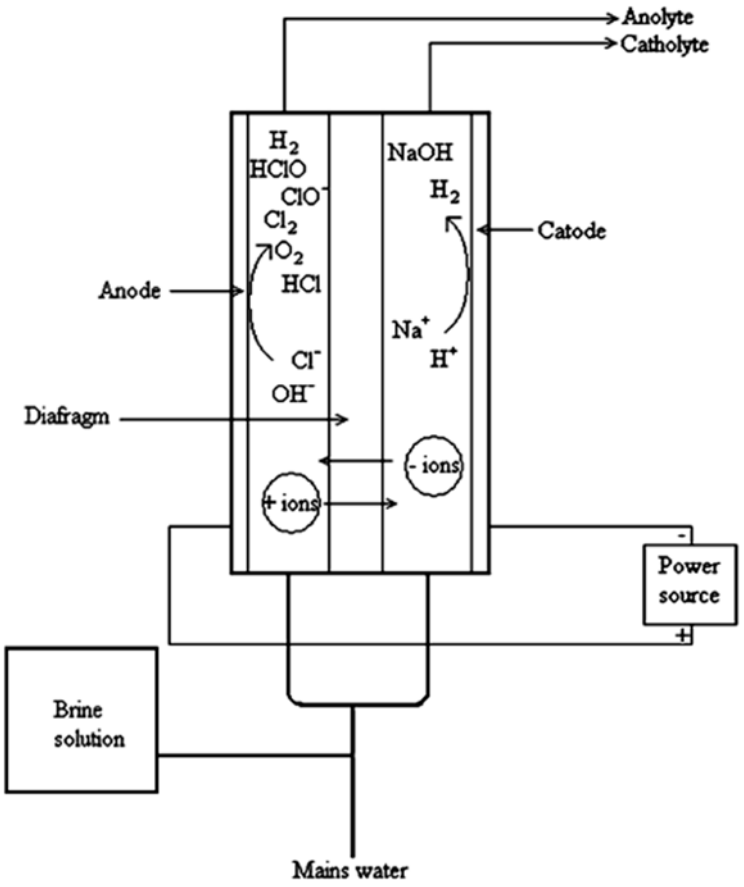

Fig. 4.1 EW production adapted from Hsu (2003)

Table 4.1 Types of stresses in fruits and vegetables

Physical stress	Chemical stress	Microbiological stress
Temperature	Enzymatic browning	Bacteria
Relative humidity	Ethylene production	Yeasts
Impact	Respiration	Molds
Cut and bruises	Chilling injury	
Insect and bird attack	Transpiration	

4.3 Peeling

Peeling is one of the integral parts of a food processing, and the majority of agricultural crops need to be peeled in order to remove at the initial stage of food processing (O'Beirne et al. 2014). Peeling removes inedible portion (peel, seeds, and stalk) of fruits and vegetables. However, the susceptibility to spoilage

increases due to acceleration of physiological process and the exposure of the tissues to microorganisms. The shelf-life and quality of fresh-cut produces could be compromised with the peeling. The goals of optimum peeling operation are (Radhakrishnaiah Setty et al. 1993):

1. Minimizing product losses,
2. Types of products e.g., potato products,
3. Minimizing heat ring formation e.g., apple, potato,
4. Minimizing energy and chemical usage, and
5. Minimizing the environmental pollution

Peeling operation can be grouped under following categories:

- Manual peeling (knife or blade),
- Mechanical peeling (abrasive devices, devices with drums, rollers, knifes or blades and milling cutters),
- Chemical peeling,
- Enzymatic peeling, and
- Thermal peeling (Flame or dry heat peeling, steam or wet heat peeling, thermal blast peeling, and vapour explosion or vacuum peeling)

4.3.1 Manual Peeling

Manual peeling is performed using stationary or rotatory hand peelers or knives against the surface of fruits and vegetables. Fresh-cut fruit and vegetables with good microbiological quality can be obtained by this method. Klaiber et al. (2005) reported that knife peeling caused less wounding in comparison to abrasion peeling in carrots. This can result lower microbial contamination after processing. On the other hand, O'Beirne et al. (2014) did not find differences between coarse abrasion and hand peeled carrot surfaces considering *E. coli* O157:H7 cells attached to the surface after peeling. However, despite of good results obtained by manual peeling, this method is limited to small scale processing and is laborious and requires more time.

4.3.2 Mechanical Peeling

Mechanical peeling includes different types of process that interact directly with skin and then removes the skin. Common commercial mechanical peelers are abrasive devices, drums, rollers, knives and milling cutters (Shirmohammadi et al. 2012). Mechanical peelers can provide high quality fresh final products and they are environmental friendly and nontoxic. The main factors affecting the peeling process are mechanical and physical properties of fruit and vegetable tissues, such as skin thickness, firmness, toughness, variety, rupture force, cutting force, maximum shearing force, shear strength, tensile strength and rupture stress

(Shirmohammadi et al. 2012). The general downside of these methods relates to the associated material loss; however, it is still preferred among the current methods. This is because it can keep edible portions of products fresh and harmless. For this reason, many attempts have been made to develop optimized process to reduce the material loss (Emadi and Yarlagadda 2006).

Singh and Shukla (1995) developed a power operated batch type mechanical peeler for potato peeling. The machine consists a peeling drum with protrusions on the inside surface and the drum rotates and then detaches peel from potatoes by abrasion. Additionally, the peeler have a water spraying unit that washes the potatoes and simultaneously peels are removed from the drum. The capacity of the machine is 100 kg/h with a peeling efficiency and peel losses of 78 % and 6 %, respectively (Singh and Shukla 1995). In the same manner, Emadi et al. (2007) developed a new abrasive peeling methods for the pumpkin. The design of the two innovative peeling devices, called abrasive pads and abrasive disks, are aimed at evenly peeling of the pumpkin uneven surfaces. In addition, they optimized the peeling process considering the convex and concave areas, and product losses with peels. The results of abrasive pads indicated the possibility of the peeling effect in concave and convex areas as 4.5 and 3.83 %/min, respectively and peel losses 0.14 %/min. These results were obtained in optimum conditions of independent variables involving 0 flap angle, overlap of 26.5 mm, 140 rpm of peeler head speed, and 10 rpm of vegetable speed (Emadi et al. 2007).

Other approaches aimed to minimize the material loss in mechanical peeling of fresh fruits and vegetables is the development of computational models to simulate tissue damage. These models show potential of improving designs and selecting optimum conditions. Modeling can provide critical analysis by understanding the deformation during peeling process (Shirmohammadi et al. 2011). Modelling of mechanical peeling of fruits and vegetables will enhance efficiency and quality and can help to reduce material loss. Another significant advantage of models is the possibility of improving the life of tools by reducing wear (Shirmohammadi et al. 2011).

4.3.3 Lye Peeling

Lye peeling is one of the oldest methods used in the food industry. This method is used mainly for peeling fruits and vegetables. It involves the immersion of a product in alkaline solution at high temperatures (90–100 °C) (Di Matteo et al. 2012). In lye peeling, the lye solution dissolves the pectic and hemicellulosic material in the cell walls by cleaving the α-(1 → 4) bond between the individual galacturonic acid units. The removal of the pectin weakens the network of cellulose microfibrils and released the skin by collapsing the skin. Finally, the removed peels were washed after the chemical peeling (Barreiro et al. 2007).

The lye peeling have been used extensively in peaches, tomato, kiwi and potato (Barreiro et al. 2007; Garcia and Barrett 2006; Gómez-López et al. 2014). The rate of peeling is a function of alkali temperature and concentration, peeling time,

geometry, peel thickness, and other characteristics of fruits. This method involves both chemical and thermal treatments (Barreiro et al. 2007). In the case of kiwifruit NaOH concentration of the lye solution led to decreased peeling time and NaOH concentration above 20 % resulted in excessive softening of fruit. This causes a complete loss of firmness. Furthermore, concentrations below 15 % NaOH were not sufficient to properly peel the kiwifruit (Gómez-López et al. 2014). In contrast, the immersion in 2.5 % NaOH boiling solution (5 min) showed the best treatment since it inhibited the enzymatic browning and intensified the natural yellow color of the cubiu fruit (*Solanum sessiliflorum* Dunal) (Caceres et al. 2012).

Di Matteo et al. (2012) evaluated the lye peeling process at low temperatures for cuticle removal from different hazelnut varieties. The collected data showed that the use of the solution with NaOH (0.4 g/100 g) and $NaH_2PO_4 \cdot H_2O$ (0.2 g/100 g) at 50 °C was effective in cuticle removal and provided a yield of peeling higher than 90 %. The chemical–physical parameters in unpeeled and peeled hazelnut samples did not show any differences in texture, sugar, protein and a-tocopherol contents, while significant changes were observed in colour and total fat. However, these changes did not influence the sensorial parameters of the peeled hazelnut samples, and the treatment was positively judged by sensory panel (Di Matteo et al. 2012).

A variant of lye peeling process is the use of KOH instead of NaOH. While KOH is generally more expensive than NaOH, but half concentration of KOH is needed to achieve equivalent result. For example, tomato peeling with NaOH at a concentration of 18 % (4.5 N) produced 79 % peeled tomatoes, while equivalent results with KOH were produced using a concentration between 12 % (2.1 N) and 14 % (2.5 N) (Das and Barringer 2006).

4.3.4 Enzymatic Peeling

Enzymatic peeling consists of treatment with a high-activity enzymatic solution containing polysaccharide hydrolytic enzymes, especially pectinases, cellulases, and hemicellulases since pectin, cellulose and hemicellulose are the polysaccharides most responsible for the adherence of the peel to the fruit. These enzymatic preparations were obtained by fermentation of genetically modified fungal microorganisms produced by biotechnological industries (Suutarinen et al. 2003).

Enzymatic peeling is mostly applied in the case of citrus fruits' peeling. The process involves manual extraction of flavedo at oranges' top and bottom poles and its segmentation through longitudinal and equatorial cuts with sharp knives. These cuts and segmentations aimed at facilitating enzyme penetration for albedo digestion inside the fruit (Barrios et al. 2014). Fruits are later dipped into 1 % pectinase solution by vacuum infusion. After vacuum, fruits are maintained at 40 °C for 15–40 min to achieve the most favourable enzymatic activity. The peels are then removed manually and fruits are washed with pressurized water (Barrios et al. 2014).

The main advantages of enzymatic peeling are its ability to produce good quality product, requirement of the reduced heat treatment and production of low industrial

waste. Murakami et al. (2012) compared the microbiological and physicochemical quality of enzymatically peeled and manually peeled persimmon fruit for fresh cut slices. The diversity as well as bacterial and fungal counts were observed low in the case of enzymatic peeling, whereas other quality parameters such as color index, pH and texture were unaffected. Their results indicated enzymatic peeling could be an alternative to knife peeling. Pretel et al. (2008) also concluded that enzymatic peeling is a good alternative to traditional chemical peeling. For oranges they recommended the optimum enzyme concentration of enzyme Peelzym be 1 ml L^{-1}, optimum temperature 35–40 °C and pH range of 3.5–4.5 (Pretel et al. 2008). In enzymatic peeling, there are some parameters to be taken into account to obtain good peeling efficiency. The most important ones are temperature, time and the ratio between peel mass and the enzyme solution volume ratio (Pagán et al. 2010).

4.3.5 Thermal Peeling

Thermal peeling is used for thick-skinned vegetables and this method can be performed by wet heat (steam) or dry heat (flame, infrared, and hot gases). Steam peeling is one of the most popular among modern methods of peeling. Its widespread application is due to its high automation, precise control of time, temperature and pressure; and reduced environmental pollution as compared to chemical peeling (Garrote et al. 2000). Steam peeling has been explained as a combination of two phenomena. First it builds up internal pressure due to high temperature which causes mechanical failure of the cell, and secondly it affects the tissue resulting the loss of rigidity and reduced turgor pressure, melting and breakdown or disorganization of the cell wall substances, such as pectin and polysaccharides (Garrote et al. 2000).

In steam peeling, vegetables are introduced in batches into a pressure vessel with steam (1,500 kPa) which rotates at a speed of 4–6 rpm. The rotation allows the vegetable surface to be treated by steam. The high temperature of the steam rapidly warms the surface of the product but it does not affect their organoleptic attributes (i.e. color, firmness, texture). The steam peeling has advantages, such as increased production capacity, reduced water consumption, and improved appearance of the product.

Flame or dry heat peeling consists of a conveyor belt that carries and rotates the vegetables through a furnace heated to 1,000 °C. The outer ‘paper shell’ and root hairs are burned off, and the charred skin is removed by high-pressure water sprays. Average product losses are usually 9 %. Dry peeling was better than wet peeling in reducing microbial populations and preserving ascorbic acid content.

4.3.6 Infrared Peeling

Infrared (IR) waves are electromagnetic spectrum with a frequency beyond of visible light. When IR waves hit a material, they are reflected, either transmitted or absorbed. Absorbed waves are transformed into heat and the internal temperature of material is increased. Infrared radiation (IR) shows a rapid surface heating, which allows effective

heating of shallow layer of the fruit or vegetable surface and it helps to separate peels while preserving the nutrients and quality of the products (Li et al. 2014b).

IR heating technique could be developed as a novel dry-peeling method for peeling fruits and vegetables since it does not require any heating medium, such as lye, water, or steam (Li et al. 2014b). Li et al. (2014b) evaluated the effectiveness of infrared dry-peeling as an alternative process for peeling tomatoes without lye and water. Compared to conventional lye peeling, IR dry-peeling using 30 s to 75 s heating time resulted in lower peeling loss (8.3 %–13.2 % vs. 12.9 %–15.8 %), thinner thickness of peeled-off skin (0.39–0.91 mm vs. 0.38–1.06 mm), and slightly firmer texture of peeled products (10.30–19.72 N vs. 9.42–13.73 N). In addition, the treatment resulted in melting of cuticular membrane, collapse of several cellular layers, and severe degradation of cell wall structures. This caused easy peel separation (Li et al. 2014a).

The efficacy of IR radiation heating for peach (i.e. cling stone peaches in three size categories) peeling was investigated under different IR heating conditions. Comparing with regular wet-lye peeling, the IR peeling method showed promising results to achieve high peel-ability (>80 mm^2/100 mm^2) and peeling yields (>90 g/100 g). This also ensured color and texture characteristics of the peeled products. Micro-structural changes induced by IR radiation in peach tissues adjacent to skins were observed as thermal expansion of cell wall and collapses of several cellular layers. This indicated mechanical difference between IR peeling and wet-lye peeling. Temperature profiles at various peach locations demonstrated a dramatic temperature increase at peach surface and relatively low temperatures in peach interior (Li et al. 2014a, b).

4.4 Cutting

Cutting, slicing, dicing, and shredding are non-thermal food operation for size reduction. This process reduces the preparation time by consumers. Cutting removes inedible and discolored portions from foods using knife, chopper and slicer (Corbo et al. 2010). However, in this food processing injured tissues are removed so that these are unavailable for microbial spread. The cut tissues results in reduced respiration and enzymes activity, thus retarding rapid spoilage and increases shelf life (Chung et al. 2011). The cutting process accumulates fluids on the cut surface, increases microbial load and enzymes activity (Das et al. 2011).

4.4.1 Enzymes Used in Cutting

The washing of fresh cut produce may be helpful in minimizing accumulation of potential substrates and enzymes (Qi et al. 2011). There is a key enzyme induced by wounds, for example phenylalanine ammonia lyase (PAL) (Du et al. 2012). This enzyme is produced by biosynthesis of the phenolic compounds during stress.

These accumulated compounds are used as substrates by polyphenol oxidase (PPO) leading to browning reactions (Garcia and Barrett 2002). It has been shown that the enzyme activity caused browning defects on the cut edges and leaves surfaces (Luna et al. 2012). Other enzyme involved in the browning process is the peroxidase (POD). This accelerates the darkening of fresh cut vegetables and fruits (Kim et al. 2014). The use of high pressure packing and organic acids can reduce the browning effect caused by these three enzymes (Jang and Moon 2011).

4.4.2 Factors Affect Cutting

Another relevant factor in the cutting process is the cutting tools (Qi et al. 2011). Sharpness of knife blades can significantly affect storage life, whereas dull knives cause bruises and damage to the tissue layers (Gil and Allende 2012).Mishra et al. (2012)reported that cutting with a sharp blade and water dipping (10 min) inhibited browning in fresh cut eggplant. They also reported enhanced shelf life of eggplant up to 5, 12 and 16 days at ambient, 10 °C and 4 °C storage, respectively. The effects of slicing and shredding of radishes were studied during storage at 1, 5, and 10 °C (del Aguila et al. 2006). On the 10th day, intact radishes stored at 1 °C showed the lowest respiration rate, while sliced radishes stored at 10 °C showed the highest. Shredded radishes showed lower soluble solids contents during storage.

In this context the sharpness of the cutting blade and the some geometric shapes, such as cylindrical should be avoided in melons (Silveira et al. 2013). Other studies for papaya cv. 'Maradol' slices stored at 10 °C and 5 °C showed a shelf life of 1 day and 2 days longer for the cubical shape (Rivera-López et al. 2005). The direction of cutting either longitudinal or transverse could influence the quality of fresh-cut fruits and vegetables Deza-Durand and Petersen (2011) demonstrated that cutting of the iceberg lettuce to its transverse direction to the mid-rib caused more severe damage to the tissue as compared to the longitudinal cuts. They assessed the quality based on aroma compounds production of lipoxygenase volatiles and their respiration rate.

The most common geometric shapes of fresh-cut vegetables and fruits are: disc, baton, cube, shred and slice. The shapes depend on the types of product and their requirement (Koidis et al. 2012). For some fruits like yellow melon and mango, it is important to determinate the types of cutting for their processing (Ngamchuachit et al. 2014; Russo et al. 2012).

Cutting also influences the nutritional quality of minimally processed fruits and vegetables. Cocetta et al. (2014) reported that ascorbic acid in spinach leaves decreased from 19.41 mg/100 g FW to 15 mg/100 g FW after cutting, and leaving the vegetables tissues exposed to oxidation. Lana and Tijskens (2006) investigated the total antioxidant activity in slices and intact tomatoes during storage at 5 °C. Cutting resulted decreased hydrophilic antioxidant activity (HAA) as compared to control fruits and it did not influence significantly the lipophilic antioxidant activity (LAA).

4.5 Emerging Technology in Fresh-Cut Fruits and Vegetables

Nowadays the tendency to preserve the processed fruits and vegetables using the emerging technologies (Mahajan et al. 2014; Singh and Alam 2012). These food processing techniques are non-thermal operations and used in the fresh-cut fruits and vegetables. The common ones are: UV-C light, pulsed electric field, edible coatings, active packing and water jet cutting (Pasha et al. 2014).

4.5.1 UV-C Irradiation

Ultraviolet light C (UV-C) is non-ionizing radiation with wave lengths from 100 to 280 nm. This light is used to maintain microbial quality, preserve hypersensitive tissues and to browning and injury of the fresh-cut products (Vicente et al. 2005). On the other hand, Costa et al. (2006) suggested that the UV-C can be used as a non-chemical process to delay tissue damages and disruptions, and to maintain its antioxidant activity in the case of broccoli.

4.5.2 Pulsed Electric Field

Pulsed electric field method consists in applying small pulses of electricity and it used to inactive the activity of microorganisms and is considered as one of the most suitable options to conserve the quality of fresh-cut products. It avoids or reduces changes in sensory and physical properties of foods (Elez-Martinez and Martin-Belloso 2007). Shayanfar et al. (2013b) showed that the application of pulsed electricity did not affect the firmness and color in the case of carrot discs. On the other hand this method did not preserve the color, but maintained of firmness of frozen potato strips (Shayanfar et al. 2013a). This indicates that the efficacy of this method varied with the types of the fresh-cut products.

4.5.3 Edible Coating

Edible coating method consists of using an editable substance applied as a film on the surface of the fruits and vegetables (Pasha et al. 2014). These coatings prevent the products from their water loss and assist to retain nutrients as well as to reduce microbial spoilage. Nowadays these techniques are being used as a potential treatment to extend the shelf life of fresh cut products. In the case of fruits and vegetables, edible coating formulations are more commonly based polysaccharides, such

as pectin, chitosan, starch and alginate (Brasil et al. 2012). This method is viable to be applied in products susceptible to oxidation like pear, apple and papayas to avoid the browning (Pilon et al. 2013).

4.5.4 Active Packing

Active packing is a smart system that includes active ingredients, like oxygen scavengers, CO_2 absorbers, ethylene absorbers. In addition active components in the packaging can be released to prevent the deteriorative reactions (Restuccia et al. 2010). The most applied active packing for fresh-cut fruits and vegetables consist of antimicrobial and antioxidant activity. The application of garlic essential oil encapsulated in cyclodextrin were effective against *Alternaria alternata* and it increased the shelf life of fresh-cut tomatoes (Ayala-Zavala et al. 2008). However, it is necessary to consider their effects on sensory and cost.

4.5.5 Water Jet Cutting

The traditional cutting systems involve knives, hopper, discs and counter shear). Food industry demands more effective cutting process (Palma-Salgado et al. 2014). The water jet cutting system controls pressure with a water barrier that prevents the movement of fluids and flushes away the potentially damaging enzymes from the tissues (Carreño-Olejua et al. 2010). The purified water increases the quality of the fresh-cut products with the absence of blades and knives; and reduces the possibility of microbial contamination and minimizes the oxidation. However, the main disadvantage of this method is its high cost and it is not compatible with sensitive fruits and vegetables.

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Chapter 5
Technologies in Fresh-Cut Fruit and Vegetables

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5.1 Introduction

Fresh-cut fruit and vegetables (FCFV) consumption has increased significantly in recent years. Because of the changes in consumer lifestyles, there is an increased demand of fresh-cut foods, which are nutritious, functional, safe, attractive, and ready-to-eat. The consumers perceive these products as the most appealing, considering their attributes, such as fresh-like appearance, taste, flavor, and convenience (Garcia and Barrett 2002). However, FCFV products are very sensitive to spoilage and microbial contamination due to the processes used for its preparations (e.g. peeling, cutting, and grating). These processes caused mechanical injury to the plant tissues and promoted biochemical changes, microbial degradation, and the consequence is the loss of quality (Ayala-Zavala et al. 2009; González-Aguilar et al. 2010a; Rico et al. 2007). However, some alternatives are proposed in order to avoid biochemical problems due to mechanical injury (e.g. immersion therapy). Furthermore, several technologies are used to preserve the quality of fresh-cut produce, for example, ultraviolet light, controlled and modified atmospheres, edible coatings, heat treatments, and use of natural compounds (Fig. 5.1) (González-Aguilar et al. 2010a).

Most technologies/treatments involve the alteration of the natural conditions of the FCFV, extending their shelf life. For instance, irradiation, modified atmospheres, and high pressures, cause damage to vital molecules of food spoilage microorganisms

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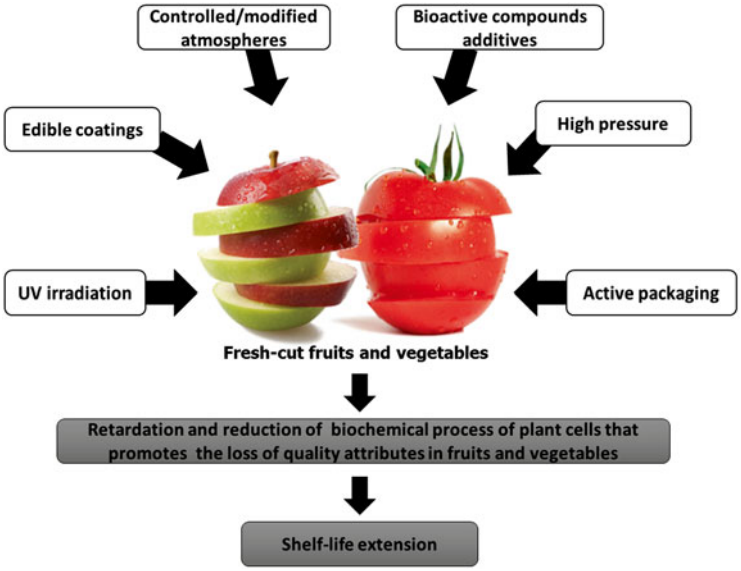

Fig. 5.1 Emerging and safe technologies to preserve quality of fresh-cut fruits and vegetables

(Charles et al. 2009; Kader et al. 1989; Norton and Sun 2008). Furthermore, edible coatings and active packaging are used to retard and reduce the biochemical process of plant cells that promotes the loss of quality. Nevertheless, some technologies used to preserve the quality of FCFV could induce some mechanisms that affect the metabolic activity of the treated produce, such as triggering of the antioxidant mechanism (González-Aguilar et al. 2010b). In addition, the innovative use of bioactive compounds as food additives could promote food's functionality as well as extend shelf life, enhance nutritional quality, and increase consumer's acceptance (Quirós-Sauceda et al. 2014; Rojas-Graü et al. 2009). This chapter describes the relevance of conventional and innovative technologies used to preserve the quality of FCFV products.

5.2 Fresh-Cut Produce: Their Biochemistry and Quality Parameters

Most of the current procedures and technologies applied in the fresh-cut industry are directed to manipulate fruit and vegetable biochemistry. For example, fruits can be divided into two groups according to their ripening mechanisms: climacteric and non-climacteric (White 2002). These differences in their biochemistry and ripening mechanisms result in different production of ethylene and respiration rates;

therefore, different storage conditions need to be maintained for preserving their quality attributes (Duque and Arrabaca 1999; Ku et al. 1999). Knowing the role of enzymatic systems during the ripening process of FCFV is essential to achieve its manipulation in order to enhance their quality parameters and shelf life (White 2002). Likewise, the complexity of produce metabolism and biochemistry is directly associated with the changes in their quality attributes. It is important to understand the ripening mechanism of the whole fresh produce in order to understand the possible changes that would occur in FCFV. For example, contemplating the effect of the respiratory process over the loss of firmness and texture of the whole produce could be useful to avoid these problems in FCFV; nevertheless, it has to be considered that the metabolic behavior of fresh produce could change after processing.

The ripening process requires large amount of energy and prolonged membrane integrity to perform catabolic and anabolic changes. In addition, the cell wall changes in terms of structure and composition, affecting firmness, metabolism of sugars and acids (flavor development), and biosynthesis of carotenoids and other pigments (color development) (Wakabayashi 2000; Merzlyak et al. 1999). Firmness is one of the most important quality attributes of FCFV, which depends on the strength and stability of cell wall. However, it is lost during the ripening process due to hydrolysis of cell wall polymers (Fischer and Bennett 1991). Considering that pectin is one of the major constituents of cell walls, its breakdown may affect cell adhesion and decrease tissue strength (Toivonen and Brummell 2008). On the other hand, other cell wall polymers are affected during the ripening process as stated by Gross and Sams (1984), these authors reported that in 15 of 17 different fruits, a total loss of non-cellulosic neutral sugars occurred during their ripening, being xylose the major neutral sugar loss. Similarly, in early stages of ripening occurred the depolymerization of xyloglucans of tomato, avocado, melon and kiwi fruit (Yakushiji et al. 2001). As stated before, this basic information can be used to reduce or delay the loss of this quality attribute in FCFV. This approach can be extrapolated to other quality parameters like appearance, texture, flavor, and nutritive value that are among the most important parameters contemplated for consumers preference (Lamikanra 2002; Kader 2002).

5.3 Impact of Processing Operations Over Fresh-Cut and Vegetables

Recently, FCFV have emerged as novel and healthy products, so that the fresh-cut industry is constantly growing, and needing to develop new technologies to reduce the undesirable effects of the processing, and preserve their fresh-like properties (Allende et al. 2006b; Soliva-Fortuny et al. 2002). Among the most common processing operations in fresh produce are the “minimal processing” technologies, which involves non-thermal methods (Manvell 1997). These are applied without

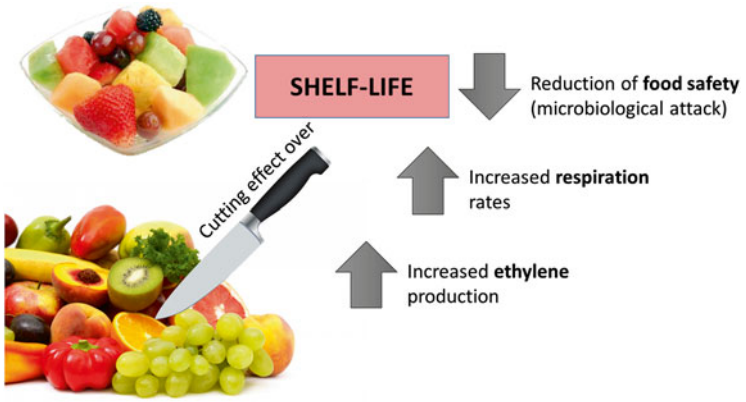

Fig. 5.2 Effect of cutting vegetable tissue over the shelf life of fresh-cut fruits and vegetables

compromising their fresh-like characteristics, and with minimal loss of color, flavor, and nutrients (Knorr et al. 2002). The replacement of the thermal technologies by the non-thermal ones is needed because in most cases, thermal energy induces various chemical reactions that lead to the quality deterioration in many foods (i.e. undesirable changes in sensory and nutritional qualities) (Ohlsson 1994). However, the minimal processing techniques such as peeling and cutting can also have a negative effect on the overall quality of FCFV; thus, reduces acceptability to the consumers due the promotion of a faster physiological deterioration, biochemical changes, and microbial degradation (Artés et al. 2007; Wiley 1994; Rolle and CHISM 1987).

Minimal processing of fruits and vegetables includes peeling, cutting, grating or trimming, and are used to obtain 100 % edible product. However, the minimal processing techniques eliminates the natural protective layer of fruits and vegetables, and promote many physical and physiological changes accelerating products decay (Fig. 5.2) (Gil and Allende 2012). In general, during minimal processing, the fruit and vegetable tissues are damaged, and many cells are broken, releasing intracellular products such as phytochemicals and enzymes (Baeza 2007; Allende et al. 2006b; Toivonen and DeEll 2002b). Nevertheless, the living tissues of FCFV need transform their stored biomolecules to maintain its "energized state" (Olarte et al. 2009). However, if respiration cannot supply enough energy to maintain its required energy state, the tissues will rapidly deteriorate and die (Olarte et al. 2009). Therefore, the loss of the "energized state" of FCFV results in loss of quality, and lower appeal to the consumers. Furthermore, on cutting or peeling of fresh produce, the outer periderm is removed and the resistance barrier to transpiration is lost, causing contamination of bacteria, yeast and moulds (Toivonen and DeEll 2002b; Allende et al. 2004; Lehto et al. 2011). Elevated respiration/transpiration rates and metabolic activities of spoilage microorganisms are the main reasons for shortened shelf life (Sinigaglia et al. 1999). In this sense, the effects of minimal processing over fruit ripening (i.e. ethylene and respiration), color changes, and food safety are discussed afterwards.

5.3.1 Ethylene Production

Ethylene (C_2H_4) is naturally produced by plants in the process of ripening of climacteric fruits; however, diseased or wounded tissue produces it in a higher levels (Yang and Oetiker 1994). The time line for the initiation of this response can range from a few minutes to an hour after wounds formation, and the maximal rates occur within 6–12 h (Toivonen and DeEll 2002a). The ethylene production is localized to tissues in the close vicinity of the wound or cutting injury. However, the response of wound tissue to ethylene production depends on the type and physiology of the tissue. For example, kiwifruit, tomatoes, winter squash, papaya and strawberry show increased ethylene production after cutting (Agar et al. 1999; Rivera-López et al. 2005; Watanabe et al. 2001; Steinite and Ievinsh 2002; Atta-Aly et al. 2000). However, cutting of pear (*Pyruscommunis* L.) not shown an increase, further, it has been found that cut pear slices have lower ethylene production as compared with whole fruit (Gorny et al. 2000; Toivonen and DeEll 2002a).

Different studies have shown that production of ethylene thru wounds in fruits is controlled by a coordinated expression of 1-aminocyclopropane-1-carboxyl acid synthase (ACCS) and ACC oxidase (ACCO) genes, the latter was revealed to have often a positive feedback control by ethylene (Druege 2006; Yu and Yang 1980; Hyodo 1991; Kato et al. 2000; Dong et al. 2001; Ayub et al. 1996). In addition, it has been reported that cutting induces ethylene production via induction by the same genes (Zheng et al. 2005). Moreover, the increase in ethylene production after damages by cutting and wounds is greater in pre-climacteric and climacteric than post-climacteric tissues. Furthermore, the ethylene production after cutting is void in non-climacteric fruits; however, this increases in climacteric fruits and may accelerate the fruit ripening (Brecht 1995). For example, the ethylene production in response to slicing in fruits like banana and cantaloupe depends on their maturity if the fruit is cut in pre or post-climacteric phase (Toivonen and DeEll 2002b; McGlasson 1969; Luna-Guzmán et al. 1999). Therefore, the maturity of the product must be considered before cutting and processing, especially for climacteric fruits.

Since ethylene production exerts its effects through metabolic reactions, the exposure of fruit tissue at their lowest recommended storage temperature will reduce the response (Woolf and Ferguson 2000). The storage temperature has an effect on wound induced ethylene production. It has been observed that storage of cantaloupe pieces at 0–25 °C completely suppressed wound-induced ethylene as compared to higher storage temperatures (Sangsuwan et al. 2008). Similar reduction in ethylene production from other fresh-cut fruits and vegetables could be expected at low post-cutting storage temperatures.

5.3.2 Respiration (Shelf Life)

Cutting operation in fresh-cut produce induces a series of complex events as a defense mechanism to repair the damage caused in the tissue (Sinigaglia et al. 1999). Besides the increased the ethylene production, respiration is one of the most

common responses to the wounds, and it is considered as an important indicator of the product shelf life (Surjadinata and Cisneros Zevallos 2003). Increased rate of ethylene production in response to cutting may stimulate the respiration and leads to a faster senescence and deterioration of vegetative tissues (Fonseca et al. 2002). The rate of respiration increase in FCFV may range between 1.2 and 7.0, depending on the produce cutting grade and storage temperature (Ahvenainen 1996). The increased respiration after cutting is due to the energized state of all living tissues. Therefore, after cutting the tissues, the increased respiration provides energy and carbon skeletons for the anabolic reactions similar to ripening (Helena Gomes et al. 2010).

The visual appearance of FCFV has also been reported to be influenced by the increased respiration rate. This process results in a depletion of the carbohydrate reserve in fruits and vegetables. As the respiration rate increases, an uncontrolled increase in O_2 consumption occurs, which is often an indication of oxidative browning (Manvell 1997). These metabolic reactions use substrate carbohydrates involved in fruit organoleptic quality such as sugars and organic acids. Hence, as the organic acids are natural pH indicators involved in fruit color, their decay may lead to changed color (FAO 1995). Additionally, the increased respiration, can alter organic acids (i.e. sugar-to-acid ratio), and may result an insipid taste of the FCFV product (Manvell 1997). Some of the effects of the metabolic changes can be diminished by storing the FCFV product at their optimal storage temperature.

5.3.3 Color Changes (Visual Appeal)

The appearance of FCFV is a decisive factor for customer acceptance, and it strongly affects the decision to buy the product (Toivonen and Brummell 2008). After minimal processing of fresh produce, the metabolic reactions that stimulate respiration and/or ethylene production result in some undesirable effects (discoloration, texture changes, faster ripening, and senescence) that affect consumer acceptability (Gil and Allende 2012). Specifically, the browning and discoloration effects are the most common undesirable changes that affect the color and consequently affect the visual appearance of fresh produce (Toivonen and Brummell 2008).

As mentioned before, during minimal processing, fresh produce undergo to different types of stress with the initiation of some decay reactions. For example, the enzymatic browning in several FCFV starts with cellular disruption, causing the release of phenolic compounds stored within the vacuoles in cell wall compartments. Once oxygen penetrates the wounded tissue, the phenolic compounds are the substrate for the enzyme Polyphenol Oxidase (PPO) (Yoruk and Marshall 2003). The PPO in the presence of oxygen can catalyse two different reactions: the hydroxylation of monophenols and the oxidation of *o*-diphenolsto o-Quinones. Once the *o*-phenols are oxidized to o-Quinones a non-enzymatic polymerization of quinines occurs, leading to the formation of melanins that are pigments of high molecular mass and dark in color (Queiroz et al. 2008).

On the other hand, changes in color may also occur due to a loss of the natural pigments presents in the fruits and vegetable tissue. Chlorophyll (green color), carotenoids (yellow to red color), anthocyanins (red, purple or blue color) and other types of pigments (blue and red color), are commonly secondary metabolites produced during maturity process and when the plant tissue undergoes different types of stress (Basak et al. 1996; Crozier et al. 2008). Therefore, the loss of these compounds result in loss of fresh produce color, e.g. the green color discoloration of lettuce due to the enzymatic browning (i.e. chlorophyll loss) (Martín-Diana et al. 2007). Likewise, the changes in anthocyanins in fresh-cut strawberries are directly affected by their storage temperature. The improper storage conditions results in the loss of the natural red and purple colors of strawberries, reducing their market acceptability (Odriozola-Serrano et al. 2009). Therefore, appropriate storage conditions and correct techniques should be considered to inhibit the enzymes responsible for color changes in all FCFV products.

5.3.4 Microbiological Contamination (Food Safety)

The FCFV offer a number of advantages over the whole produce; however, the fresh-cut industry and the evolving processes used to maintain freshness face considerable challenges. Among the main problems are the high spoilage rates associated to the high metabolic activity and microbial contamination. The fresh-cut produce are full of juices and rich in nutrients, which promotes the microbial growth (Brecht 2006). When a whole fruit is cut or sliced, the layer protection afforded by the fruit skin is lost, leaving the fruit tissue susceptible to pathogens attack and water loss (Ayala-Zavala et al. 2008a). In addition, lack of sanitization or pre-harvest management of fruits, make them excellent carriers of pathogenic microorganisms that often lead to outbreaks of food borne illness (Joshi et al. 2013).

The risk of microbial contamination after cutting or wounding processes is higher than those of fresh/whole fruits and vegetables (Harris et al. 2003). This high risk resides in two major factors: the high water content and the wound caused to the tissues (Saranraj 2012). When tissues are wounded either by slicing, cutting or peeling, their release nutrients that attracts and enhance the microbial growth (including mesophilic bacteria, coliforms, yeast and moulds) (Olaimat and Holley 2012). Once the microorganisms grow in the FCFV surface they can form biofilms, and their elimination and disinfection become much more difficult (Wirtanen et al. 2001). The microbial biofilms are complex structures in which bacterial populations are enclosed in a cell matrix, forming aggregates by adhering to each other or to the food matrix (Costerton et al. 1995). However, the ability to attach, grow and spread to any surface within a biofilm is almost ubiquitous among bacteria (Van Houdt and Michiels 2010). The cells associated with the biofilms have advantages in growth and survival over planktonic cells. These advantages are due to the formation of exopolysaccharide (EPS) matrix, which surrounds the biofilm. The EPS matrix is a protective mechanism of bacteria against their environment, therefore, it protects the biofilm from sanitizers and supplies nutrients (James et al. 1995).

Nevertheless, the proliferation of biofilm formation by microorganisms on fresh-cut produce is currently retarded or inhibited by using antimicrobial substances as natural organic acids and plant essential oils (Rojas-Grau and Martin-Belloso 2008; Ayala-Zavala et al. 2008c, 2009; Senhaji et al. 2007; Viuda-Martos et al. 2008). Furthermore, some treatments are used in combination with these substances, such as surface treatments or dipping fruit pieces for edible coatings. In addition, in order to reduce microbial contamination and foodborne risks, packaging guidelines for minimally processed FCFV must be followed (Pasha et al. 2014).

5.4 Emerging Technologies in Preservation of Fresh-Cut Quality Parameters

FCFV are very susceptible to quality loss in terms of sensorial, microbial and nutritional parameters. As mentioned earlier, the major causes of quality loss are attributed to the processing operations (cutting, trimming or peeling), elevated ethylene production, and respiration rates (González-Aguilar et al. 2010a, b). Therefore, the maintenance of quality attributes of these products is a big challenge. Hence, some emerging technologies including UV irradiation, controlled atmosphere, pulsed electric field, high pressure, edible coatings, and active packaging have been suggested to preserve and improve the quality of FCFV (Table 5.1).

5.4.1 UV Irradiation

Ultraviolet light (UV) is a type of non-ionizing radiation with wavelengths from 100 to 400 nm. This is usually classified into three types: UV-A (315–400 nm), UV-B (280–315 nm) and UV-C (100–280 nm). UV-C irradiation has its maximum at 254 nm and it has one of the highest germicidal action, and mostly used for surface decontamination, and controlling microorganism, thus preserve the quality in whole and FCFV products (Vicente et al. 2005; González-Aguilar et al. 2010a). It has been reported that low doses of UV-C irradiation stimulate beneficial reactions in biological systems, and this phenomenon is known as *hormesis*. These effects include delay of senescence and fruit ripening, induction of natural defenses and elicitors against fungi and bacteria (González-Aguilar et al. 2010b).

The induction of resistance against pathogens by irradiation of UV-C is correlated with the activation of the plant defense mechanism, and microbial DNA damage (González-Aguilar et al. 2007b). The treatment induces a stress that stimulates the production of phenylalanine ammonia-lyase (PAL), an enzyme that plays a key role in the synthesis of antifungal chemical species such as phytoalexins (scoparone and Resveratrol), flavonoids, and degrading fungal cell-wall enzymes (chitinases, glucanases) (Charles et al. 2009; El-Ghaouth et al. 1998). The stimulation of the plant defense system can also trigger the accumulation of these compounds and

Table 5.1 Use of emerging technologies in preservation of fresh-cut fruit and vegetables quality parameters

Type of fresh–cut product	Treatment conditions	Effect	References
UV irradiation			
"Tommy Atkins" mango	UV-C irradiation for 1 to 10 min at 5 °C	Chilling injury symptoms and deterioration was reduced. Antioxidant capacity was improved	González-Aguilar et al. (2007b)
Bell pepper	7 kJ m^{-2} UV-C light at 10 °C	Reduction of chilling injury incidence and severity	Vicente et al. (2005)
Watermelon cubes	4.1 kJ m^{-2} UV-C light	Reduction of microbial populations, keeping quality of the product	Fonseca and Rushing (2006)
	1.6 and 2.8 kJ m^{-2} UV-C light stored at 5 °C during 8 days		Artés-Hernández et al. (2010)
Melon	Cubes cut under 20 W/m^2 and exposed to 1,200 J/m^2 UV-C light and stored at 6 °C	2 log reduction for microbial counts, compared than untreated sample	Manzocco et al. (2011)
Peaches	UV-C irradiation (250–280 nm) for 3,5 and 10 min stored for 14 and 21 days at 5 °C	Significantly reduced chilling injury, increasing the resistance of fruit deterioration	González Aguilar et al. (2004)
"Haden" mango	UV-C irradiation energy levels of 2.46 and 4.93 kJ m^{-2} for 10 min and stored at 25 °C	Reduced the decay, improved the general appearance and reduced the number of fungal infections	González-Aguilar et al. (2007a)
Controlled/modified atmospheres			
Cantaloupe	Film-sealed containers flushed with 4 kPa O_2 plus 10 kPa CO_2 and stored at 5 °C	Shelf life of cubes for 9 days showing better color retention, reduced translucency, respiration rate and microbial population	Bai et al. (2001)
"Tommy Atkins" and "Kent" mango cubes	Mango cubes placed on a plastic screen and flushed with 4 kPa O_2 plus 10 kPa CO_2 (for "Tommy Atkins") and 2 kPa O_2 plus 10 kPa CO_2 (for "Kent"), then were stored at 10 °C	The marketable period was extended by 1–2 days	Rattanapanone et al. (2001)

(continued)

Table 5.1 (continued)

Type of fresh–cut product	Treatment conditions	Effect	References
Watercress	Samples placed in plastic container in a humidified atmosphere (nitrogen argon, helium, nitric dioxide and air) for 13 days at 5 °C	The respiratory rate and microbial growth was reduced up to 3 days of storage and no significant effects were observed on C_2H_4 production	Silveira et al. (2014)
Apple slices	Slices were dipped in calcium ascorbate (6 or 12 %) and stored under vacuum for 28 days at 4 °C	Significant improvement in quality as measured by sensory, chemical and visual properties. The shelf life was of 21–28 days	Aguayo et al. (2010)
High pressure			
Cut apple	High pressure (150 MPa) flushed with argon and stored at 4 °C for 2 weeks	Respiration rate and ethylene production were lower; also, the browning and microbial growth were delay	Wu et al. (2012b)
Carrots	High pressure carbon dioxide (5 MPa) at 20 °C for 20 min	1.86 $\log_{10}$ cycle reduction for aerobic bacteria and 1.25 for yeasts and molds were achieved	Bi et al. (2011)
Pineapple	Combination of pressure-time of high pressure argon treatment at 1.8 MPa for 60 min and stored at 4 °C for 20 days	Delayed the microbial growth and shelf life extension of 6 days was achieved during cold storage	Wu et al. (2012a)
Avocado slices	> 300 MPa at 20 °C for 17 h	Reduction of respiration rates and ethylene production 1 h after treatment. Also, some peroxidase activity reduction	Woolf et al. (2013)
Edible coatings			
Apple slices	Apples slices coated with alginate-apple puree edible coatings with the addition of lemongrass, oregano oil and vanillin and stored for 21 days at 4 °C	Reduction in the rates of O_2 depletion and CO_2 production. Inhibition of the growth of psychrophilic aerobes yeasts and molds	Rojas-Graü et al. (2007)

(continued)

Table 5.1 (continued)

Type of fresh–cut product	Treatment conditions	Effect	References
Melon	Slices coated with alginate, pectin and gellan-based during 15 days at 4 °C	Increased water vapor resistance, preventing dehydration. Also, an inhibitory effect on ethylene production and a reduced of the wounding stress	Oms-Oliu et al. (2008b)
Pear	Alginate-based, pectin-based and gellan-based edible coatings containing *N*-acetylcysteine at 0.75 % (w/v) and glutathione at 0.75 % (w/v) stored for 14 days at 4 °C	Increased water vapor resistance and reduced ethylene production. The incorporation of additives reduced microbial growth and browning for 2 weeks without affecting firmness	Oms-Oliu et al. (2008a)
"Kent" mango	Samples coated with alginate-based edible coating as carrier of ascorbic and citric acid and stored at 4 °C	Maintained higher color values of fresh-cut fruit and increased the antioxidant potential	Robles-Sánchez et al. (2013)
Mango	Mucilage-oil coating in fresh-cut mango slices during 9 days at 6 °C	Treatment retards loss of ascorbic acid and the drop in sensory acceptability, fewer changes in color and decreases activity POD enzyme. Also, inhibited the decay incidence and slowed microbial growth	Alikhani (2014)
Active packaging			
Strawberry	Samples were packed with low-dose of chlorine dioxide (5 ppm) sachets for 3 weeks at 4 °C	Titratable acidity retention and maintaining brightness values	Aday and Caner (2011)
Tomato	Tomato slices were packaged with garlic oil capsule sachets and exposed to 100 % humidity during 5 weeks at 5 °C	The release of garlic oil from capsules reduced microbial growth and preserved sensory quality	Ayala-Zavala et al. (2010)
Spinach	Allylisothiocyanate vapor was encapsulated in calcium alginate and used as packaging system on spinach leaves at 25 °C	Antimicrobial effects against Escherichia coli O157:H7 and molds and yeasts	Seo et al. (2012)

other phytochemicals such as carotenoids and vitamin C, which exhibit antioxidant potential, and improve the nutritional status of the products (González-Aguilar et al. 2007a, b). However, in addition to the above physiological effects produced by UV-C irradiation, there is also damage to the microbial DNA.

Several studies have been published on UV-C as a method to preserve the quality of different FCFV. Pre-storage application of UV-C reduced chilling injury in pepper (Vicente et al. 2005), delayed senescence yellowing, chlorophyll degradation, and pheophytin accumulation in broccoli (Costa et al. 2006). Likewise, its application can control the storage rot in strawberry, reduced pathogen growth and induced disease resistance in other fresh produce (Rivera-Pastrana et al. 2013; Bu et al. 2013; Bonomelli et al. 2004). Chilling injury symptoms and deterioration of "Tommy Atkins" mangoes were reduced by UV-C irradiation during storage at 5 °C (González-Aguilar et al. 2007b). In addition, the effect of short UV-C doses (0.4–8.14 kJ m^{-2}) over the shelf life of the processed lettuce was studied (Allende et al. 2006a). UV-C effectively delays the senescence and deterioration of fresh-processed lettuce during storage (Allende et al. 2004, 2006a).

5.4.2 Controlled/Modified Atmospheres

Some of the technologies used to preserve the quality of the FCFV are the controlled and modified atmospheres (CA/MA), and their beneficial effects have been well documented (Yahia 2010). CA/MA is a passive or active dynamic process that consists in altering the gases surrounding a commodity to produce a composition different from that of air. This is achieved by the interaction between two processes; the respiration rate of the fresh-cut product and the transfer of gases through the packing material (Caleb et al. 2012). Low levels of O_2 and high levels of CO_2 reduce respiration rates and help to delay senescence, thus extends the storage life and maintain nutritional and sensory quality of the fresh-cut produce (Yahia 2010; González-Aguilar et al. 2010b).

Passive CA/MA can be generated inside a package by relying on the natural respiration of produce and film permeability to attain the desired gas composition over time (Charles et al. 2003). While, active CA/MA implies a rapid process of gas replacement or displacement, or the use of gas scavengers or absorbers to establish a desired gas mixture within a package. This involves the addition of active agents into a packaged food product, such as O_2, CO_2 and ethylene scavengers (Kader et al. 1989). Once the package is closed, no further control on the gas composition is required, and the composition will inevitably change due to FCFV respiration and film gas permeability. However, the positive effects of CA/MA depend on several factors such as type of FCFV, concentrations of gases, temperature, and duration of storage (González-Aguilar et al. 2010b). Extremely low levels of O_2 and high CO_2 favors fermentative processes, which might cause the formation of acetaldehyde and the occurrence of off-flavor compounds (Thompson 2010).

Therefore, the atmospheric concentrations recommended for preservation depend on the products. In general, FCFV are more tolerant to higher CO_2 concentrations than intact products, because of the smaller diffusion resistance.

5.4.3 High Pressure Processing

High pressure processing (HPP) is a method that has shown great potential in the preservation of FCFV industry. HPP at refrigeration, ambient or moderate heating temperature allows inactivation of pathogenic and spoilage microorganism, and it can play a key role in the extending of the shelf life of fresh-cut produces (Norton and Sun 2008). In addition, HPP has been considered as an alternative for inactivation of enzymes, such as polyphenols oxidases (PPO) (Garcia and Barrett 2002). An important advantage of this technology is that HPP acts uniformly throughout a food, regardless of size, shape and geometry, and also has minimal effects on the taste, flavor, texture, appearance, and nutritional values of food (Norton and Sun 2008; Manas and Pagán 2005).

In general, microbial inactivation provided by HPP mainly targets cell membranes of treated cells, but in some cases, additional damages occur, such as extensive solute loss during pressure treatment, protein denaturation and key enzyme inactivation (Manas and Pagán 2005; Norton and Sun 2008). Nevertheless, an effective preservation has been reported from combinations of HPP with other processing techniques, such as pH, pulsed electric fields and with CO_2 (Raso and Barbosa-Cánovas 2003). Furthermore, when used in conjunction with mild thermal processes, HPP has been found to significantly increase the inactivation of bacterial spores.

5.4.4 Edible Coatings

Edible coatings have been used in the fresh-cut industry as an emerging technology to reduce the deleterious effects that minimal processing imposes on intact fruit and vegetable tissues. An edible coating is defined as a thin layer of edible material applied to the surface of food products to extend its shelf life, by reducing moisture and solute migration, gas exchange, respiration, and oxidative rates, as well as by reducing or even suppressing physiological disorders (Quirós-Sauceda et al. 2014; Kester and Fennema 1986). Compounds most commonly used to form edible coatings include chitosan, starch, cellulose, alginate, carrageenan, zein, gluten, whey, carnauba, beeswax and fatty acids (González-Aguilar et al. 2010a). Coatings with selective permeability to gases are capable of decreasing the interchange of O_2 and CO_2 between coated FCFV and the environment, thereby, slowing down the metabolic activity by decreasing the internal O_2 concentration and increasing CO_2 concentration (Olivas and Barbosa-Cánovas 2005). Therefore, in fresh-cut produce, edible

coatings decrease respiration and senescence while protecting aroma, texture and color throughout the storage (González-Aguilar et al. 2010a). However, although reduction of gas transfer from the product to the environment is desirable, extremely impermeable coatings may induce anaerobic conditions that can lead to a decrease in the production of characteristic aroma and volatile compounds (Olivas and Barbosa-Cánovas 2005).

Nevertheless, the use of the edible coatings can have more innovative uses beyond their current applications. Edible coatings can be utilized as encapsulating matrices of many bioactive compounds to improve the quality of FCFV. This could allow a controlled release of bioactive compounds so they could be available at a desired time with a specific rate (Quirós-Sauceda et al. 2014; Rojas-Graü et al. 2009). The most common bioactive compounds incorporated to coatings are antioxidants, antimicrobials, flavors and probiotics. This application is an interesting tool to extend shelf life, and to reduce the risk of pathogen growth on food surfaces, thus it could provide a functional product with health benefits (Rojas-Graü et al. 2009). In addition, the encapsulation of bioactive compounds into edible coatings can protect these additives against diverse environmental factors.

5.4.5 Active Packaging

Active packaging plays an additional role in maintaining the quality and safety of fresh-cut produce as compared to the traditional packaging. The active packaging systems are specifically designed to control product's deteriorative reactions, and to maintain the nutritional, and sensory qualities of foods. This method use active ingredients in the packaging material or the headspace (Ayala-Zavala et al. 2008b; Ozdemir and Floros 2004). In general, an active packaging is defined as an intelligent or smart system that involves interactions between package or components inside of an internal gas atmosphere (Ozdemir and Floros 2004; Floros et al. 1997). Important examples of active ingredients include oxygen scavengers, carbon dioxide emitter/absorbers, moisture absorbers, ethylene absorbers, ethanol emitters, flavor releasing/absorbing systems, time-temperature indicators, and antimicrobial films. Besides the incorporation of individual agents, the active packaging system could be more sophisticated, and have a multifunctional active system with the addition of two or more active ingredients (Ozdemir and Floros 2004). The migration of the active compounds may be achieved by direct contact between food and the packaging material or through gas phase diffusion from the inner packaging layer to the food surface (Mehyar and Han 2011).

Currently, most active packaging technologies for fruits and vegetables depend on sachet technology, which contains the active ingredients inside small bags placed in the food package (Mehyar and Han 2011). However, sachets have low consumer acceptance due to possible accidental ingestion of their contents. In addition, the high moisture content and high transpiration rate of FCFV may lead to the dissolution of the hydrophilic toxic sachet contents. Therefore, active film/container is more appropriate for FCFV products (Kerry and Butler 2008).

5.5 Bioactive Compounds as Additives to Extend Shelf Life

As discussed earlier fresh-cut produce are spoiled easier than the raw product. In brief, there are two major issues to be considered in order to extend their shelf life; first is the visual appearance, and second is their safety. So far, we have mentioned some of the most common changes in FCFV products once fresh produce undergo stress by the minimal processing techniques, and emerging technologies applied in FCFV to diminish those changes. Recently, novel technologies applied in the food industry involve the use of natural compounds with bioactive properties. This enhances the shelf life by protecting the FCFV products from microbial contamination. In this context, several research projects have asserted that phytochemicals could enhance or extend the shelf life of FCFV products (Schieber et al. 2001; Wijngaard et al. 2009, 2012).

Different organic acids such as citric acid, lactic acid, and ascorbic acid are usually applied as a dip. These are strong antimicrobial agents against psychrophilic and mesophilic microorganisms in fresh produce (Uyttendaele et al. 2004; Bari et al. 2005). Likewise, some natural bioactive compounds, such as ascorbic acid, N-acetylcysteine and 4-hexylresorcinol, are used in order to protect the color of FCFV products (Rojas-Graü et al. 2006; González-Aguilar et al. 2001). However, the most common bioactive compounds with proven efficacy are volatile compounds, essential oils, and phenolic compounds (Fig. 5.3) (Ayala-Zavala et al. 2011). These compounds extend the shelf life of FCFV as well as provide health benefits (Ayala-Zavala et al. 2008b, d; González-Aguilar et al. 2010a).

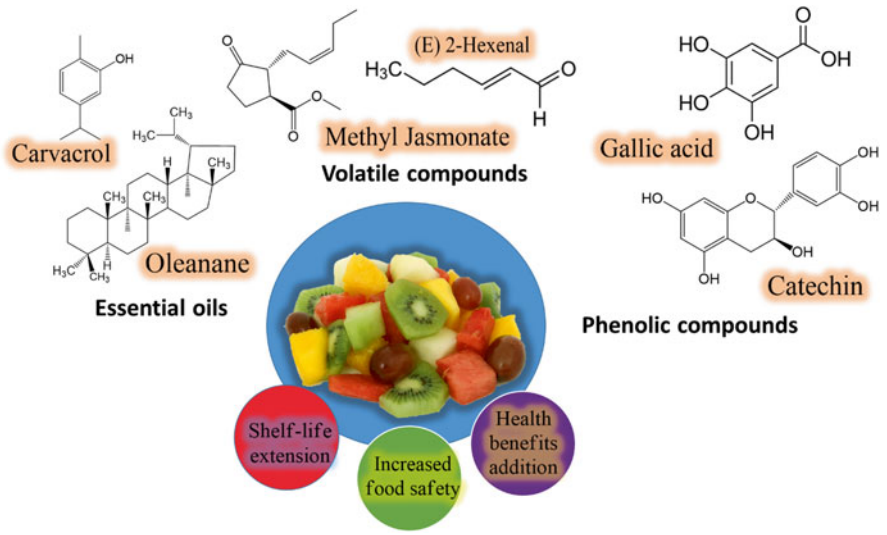

Fig. 5.3 Benefits in application of the most common bioactive compounds as additives in fresh-cut products

5.5.1 Volatile Compounds

Volatiles are low molecular weight organic compounds (less 250 g/Mol) with high vapor pressure at room temperature (Hewett et al. 1998). Plants produce a wide range of volatile compounds, some are important for flavor quality in fruits, vegetables, spices, and herbs, and are generally recognized as safe (GRAS) (Kays 1991). The volatile and semi-volatile compounds in plant constituents play important roles in the plant growth, such as plant-plant competition and cooperative co-evolution, plant's defense against insects, pests, herbivores and pathogens (Yang et al. 2013). Some studies have shown that the exposure of some fresh-cut products to volatile compounds, such as methyl jasmonate, can significantly reduce the risk of microbial contamination (Wang and Buta 2003; González-Aguilar et al. 2010b). Additionally, these volatile compounds also reduce the browning effects after cutting the tissues of fresh produce, and prevents the damage by chilling injury (Wang and Buta 2003).

Moreover, it has been shown that the application (E) 2-hexanal prevents microbial contamination of the FCFV products, especially against *Botrytis cinerea* and *Aspergillus flavus* (Gardini et al. 2001; Fallik et al. 1998). Likewise, the compounds released by plant tissue through lipoxygenase pathway, such as six carbon aldehydes, have been found to inhibit hyphal growth of *Alternaria alternate* and *B. cinerea* (González-Aguilar et al. 2010b). Furthermore, volatiles compounds such as jasmonates have been used as elicitors as they play key roles as signal molecules in plant defense responses against biotic stress (microbial contamination). These also induce the synthesis of antioxidants such as vitamin C and phenolic compounds (Solis et al. 2004).

5.5.2 Essential Oils

The most studied bioactive compounds applied to fresh-cut products are essential oils (EOs). These are volatile and natural complex compounds characterized by a strong odor, and are formed by aromatic plants as a secondary metabolites (Bakkali et al. 2008). EOs represent the most important aromatic fraction of plant and vegetal tissues. These compounds are constituted by a complex mixture of terpenes, alcohols, ketones, aldehydes and esters. The most common constituents within EO are terpenes. They are made from combinations of several 5-carbon-base (C5) units called isoprene. Terpenes or terpenoids are active against bacteria, fungi, virus, and protozoa (Scortichini and Rossi 1991; Inoue et al. 2004; Dalleau et al. 2008; Solis et al. 2004; Herman 1992). It was reported that 60 % of EOs derivatives examined to date were inhibitory to fungi, while 30 % inhibited bacteria (Chaurasia and Vyas 1977).

However, the mechanisms of antimicrobial activity are not fully elucidated. The general accepted hypothesis establishes that the components of EOs acts in several targets of the bacterial cell. For example, the hydrophobicity of EOs enables them to partition in the lipids of the cell membrane and mitochondria,

rendering them permeable and leading to leakage of cell contents (Cox et al. 2000). Physico-chemical conditions that improve the action of EOs are low pH, low temperature, and low oxygen levels (Burt 2004). However, EO's treatments can affect the aroma and sensory properties of the fresh-cut product. EO of citrus fruits such as mandarin, cider, and lime preserved the quality of fresh-cut fruit and salads without affecting consumer acceptance (Lanciotti et al. 2004). Therefore, the addition of these bioactive compounds to FCFV products represents an excellent choice to extend their shelf life and consumer acceptance.

5.5.3 Phenolic Compounds

Phenolic compounds comprise a wide and diverse group of molecules classified as secondary metabolites in plants. These compounds have a large range of structures and functions (Haminiuk et al. 2012). Phenolic compounds are considered as important plant secondary metabolites due to their abundance and beneficial properties. These substances are synthesized during the normal development of the plant and once the plant tissue undergoes diverse types of stress, their synthesis is triggered (Naczk and Shahidi 2004). More than 8,000 different phenolic compounds have been identified in 16 different classes with diverse chemical structures and molecular weight (Velderrain-Rodríguez et al. 2014). Among those different classes of phenolic compounds, phenolic acids and flavonoids are the most studied as food additives.

The flavonoids have been identified as an excellent food additive capable of ensure food safety by preventing the microbial attack in FCFV (Weidenbörner et al. 1990). It has been shown that flavonoids can protect fresh produce against spoilage fungi, such as *Fusarium oxysporum* (banana and grape), *Aspergillus japonicus* (pokhara and apricot), *Aspergillus oryzae*(orange), *Aspergillus awamori* (lemon), *Aspergillus phoenicis* (tomato), *Aspergillus tubingensis* (peach), *Aspergillus niger* (apple), *Aspergillus flavus* (mango), *Aspergillus foetidus* (kiwi) and *Rhizopus stolonifer* (date) (Sharma and Kumar 2009; Wanchaitanawong et al. 2005; Al-Hindi et al. 2011). The phenolic compounds have also the ability to interfere with cellular metabolic activity. The most common proposed mechanisms include substrate complex formation, membrane disruption, enzyme inactivation and metal chelation (Holley and Patel 2005). However, due to their proven antimicrobial activity, these compounds have been recently applied as food additives within diverse matrixes, such as edible coatings.

The phenolic compounds as applied in meat products. For example, tea catechins were found to be more efficient than α-tocopherol (both applied at 300 mg/kg level) in the inhibition of minced muscle lipid oxidation in fresh meats, poultry and fish. However, the changes in color of FCFV can be prevented using phenolic compounds. As well as other non-phenolic compounds (i.e. citric and malic acid), some phenolic compounds such as phenolic acids and anthocyanins are capable of lower the pH of a system. This can reduce the browning produced by the PPO activity

(Ayala-Zavala et al. 2011; Williams and Hrazdina 1979). Moreover, anthocyanins are applied as colorants in food products (Stintzing and Carle 2004). Furthermore, the information about phenolic compounds are in abundance, thus it makes them more attractive as food additives (Schieber et al. 2001; Wijngaard et al. 2012; Ayala-Zavala et al. 2010; Joana Gil-Chávez et al. 2013). Hence, the fresh-cut industry could prevent several economic losses by extracting phenolic compounds from different by-products, such as peels, seeds, and unused flesh.

5.6 Conclusion

The consumer awareness about the healthy diet and its benefits has increased the demand of FCFV. However, the minimal processing applied to fresh-cut produce accelerates the ripening processes and renders them susceptible to microbial contamination, resulting in a short shelf life. Recently, some studies have been focused on reducing the undesirable effects of minimal processing such as cutting or peeling on the quality of FCFV. The elucidation of the mechanisms that lead fruits and vegetables to spoilage once they are subjected to minimal processing, enables the fresh-cut industry to develop and apply efficient methods to extend shelf life to preserve the quality of the products, and hence, the consumers acceptance. Emerging technologies such as UV irradiation, controlled atmospheres, high-pressure processing, edible coatings, and active packaging are applied to diminish the undesirable effects of minimal processing, thereby keeping the quality of fresh-cut produce for a longer period. Likewise, natural bioactive compounds such as fruit and vegetable phytochemicals, besides extending the shelf life and provide diverse health benefits, could prevent microbial spoilage of FCFV.

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Chapter 6
Trends, Convenience, and Safety Issues of Ready Meals

Ida Idayu Muhamad and Norsuhada Abdul Karim

6.1 Introduction: An Overview

Today's food industry and retailers are trying to address the growing demand for convenience by considerable expansion of pre-prepared meal solutions, for example ready meals (also called meals ready-to-eat, MRE) (Geeroms et al. 2008; Olsen et al. 2010). Due to the socio-economic evolutions and the busy and hectic lifestyle, ready meals have become a popular meal solution for many people around the world. Based on the retail value of US$92.2 billion in 2012, Euromonitor International (2013) has pointed that ready meal secures a noteworthy market and it is expected to maintain this momentum in the forthcoming years up to 2016.

6.1.1 History of Ready Meals

In September 1917, the food division of the surgeon general's office was established for the safeguard of the nutritional interests of the USA army. The initial task of this office was to investigate the complaints of apparent food wastage in the army camps and to ensure the nutritional requirements of US soldiers. The results of this department's early investigation led to the creation of a training ration that would satisfy the soldier's appetite, increase efficiency, provide balanced nutrition. These meals could be centrally obtained via the quartermaster and could provide financial savings to the government. These are the basic tenets of ration design. The concept of hot food and drinking water delivery to troops in the trenches of the battlefield was

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pioneered during World War I. The trench ration consisted of basic items including hard bread, various beef products, sardines, coffee, salt, and sugar. Advancements over time include the packaging of ration contents in sealed galvanized tins to protect them from gas, spoilage, and dampness (Feagans et al. 2010).

During World War II the primary ration was the so-called "combat-individual" (C-ration). There were 23 different rations to be consumed for up to 90 days, but troops generally had an aversion to them because of menu monotony and poor nutrition. During the Korean War, soldiers were forced to continue eating C-rations because of the surplus from World War II. Another type, the K-ration was the most nutritionally balanced ration was also developed for paratroopers to carry in their pockets. However, advancements in 1958 included the meal, combat-individual (MCI), which included 12 menus, averaging 1,200 cal each. The Vietnam era steered new processing and packaging techniques derived from NASA research. The long range patrol (LRP) ration was added, metal containers were phased out, and cigarettes were removed. To this point, design of military rations was based on the idea that the majority of a soldier's load should consist of weapons and ammunition, rather than food ration. Consequently, the caloric content decreased while the caloric density increased with high fat and lower water content. Successive generations of ration design have occurred over time, leading to the development of MRE in the 1980s (Feagans et al. 2010).

The ready meals went into full production in 1980, and ready meals were in the market by 1983. The ready meals have gone through frequent developmental changes and it consists of 24 varieties of meals to accommodate diverse tastes. Each meal contains an entrée, starch, spread, dessert, snack, beverage, hot beverage bag, accessory packet, plastic spoon, and flameless ration heater. The design of the MRE allows extended storage under ideal conditions (up to 130 months at 15.6 °C) and provides easy meal preparation as well as safety (Feagans et al. 2010).

6.1.2 Definition of Ready Meals

Ready meals (meals, ready-to-eat, MRE or ready-to-eat meals, RTE) can be broadly defined as complex assemblages of precooked foodstuffs, packaged together and sold through the refrigerated retail chain. These are considered as a rapid meal solution to the consumers (Spencer 2005). Other researchers defined the ready meals as complete meals that require few or no extra ingredients, and these could replace the main course home-made main meal (Costa et al. 2001; Mahon et al. 2006; Geeroms et al. 2008). Nielsen (2006) defined the ready-to-eat (RTE) meals as frozen or fresh, hot or cold, fully prepared meals, which could be purchased from a store and could be eaten elsewhere. Pandrangi and Balasubramaniam (2005) defined the ready meals that require minimal preparation before consumption. The definition of ready meals is inconsistent, but the food industry sometimes defines it as a pre-prepared main course that can be reheated in its container, requires no further ingredients, and needs only minimal preparation before consumption (Howard et al. 2012).

Table 6.1 Classification of ready meals

Types of ready meals	Description
Chilled ready meals	A chilled product is portioned, cooked and then chilled to 3 °C or prepared food that is stored at refrigeration temperatures which are at or below 8 °C and can be preserved for up to 4 days
	Chilled foods defined as perishable foods and they are extended shelf life products with wholesome
	Kept within specified ranges of temperature above −1 °C (IFST 1990; Denis and Stringer 2000)
Frozen ready meals	A frozen product is is preserved by freezing and can be preserved for up to 12 months depending on the types
	Defined as complete meals which need no additional ingredients as opposed to part meals also known as 'meal centers' such as fish portions, fish fingers and pies to which consumers can add vegetables, pasta or rice
Dried ready meals	Drying is a method of food preservation that works by removing water from the food, which inhibits the growth of bacteria and has been practiced worldwide since ancient times
	Examples: Dried processed foods (instant coffee/milo/tea, instant noodles, instant soup, bouillon cube, powdered milk, oatmeal, sugar), Dried plants (fruits, vegetables, seeds, herbs), Dried fungi (mushrooms), Dried animals (fish, seafood, meat)
Canned ready meals	Canning is the process of applying heat to food that sealed in a jar in order to destroy any microorganisms causing food spoilage
	Proper canning techniques stop this spoilage by heating the food for a specific period of time and killing these unwanted microorganisms
	During the canning process, air is driven from the jar and a vacuum is formed as the jar cools and seals
Ambient stable ready meals	Shelf stable food (sometimes called ambient food) is normally be stored refrigerated and it can be processed in such a way so that it can safely store in a sealed container at room or ambient temperature

Ready meals are different from take-away and fast-food, or canned food. Ready meals should be distinguished from ready-to-eat take-away foods, as the former type meal still requires some cooking or re-heating prior to serving whereas with take-away foods need no cooking or heating (Verlegh and Candel 1999; Geeroms et al. 2008).

6.1.3 Types of Ready Meals

Ready meals can be classified into five categories: dried, canned, ambient stable, chilled and frozen (Table 6.1). Ranges of dried meals, typically with an Indian or Chinese image, such as curries and chow mein, appeared in the 1950s in the market. A range of canned meals such as chili-con-carne, spaghetti bolognaise, and chicken

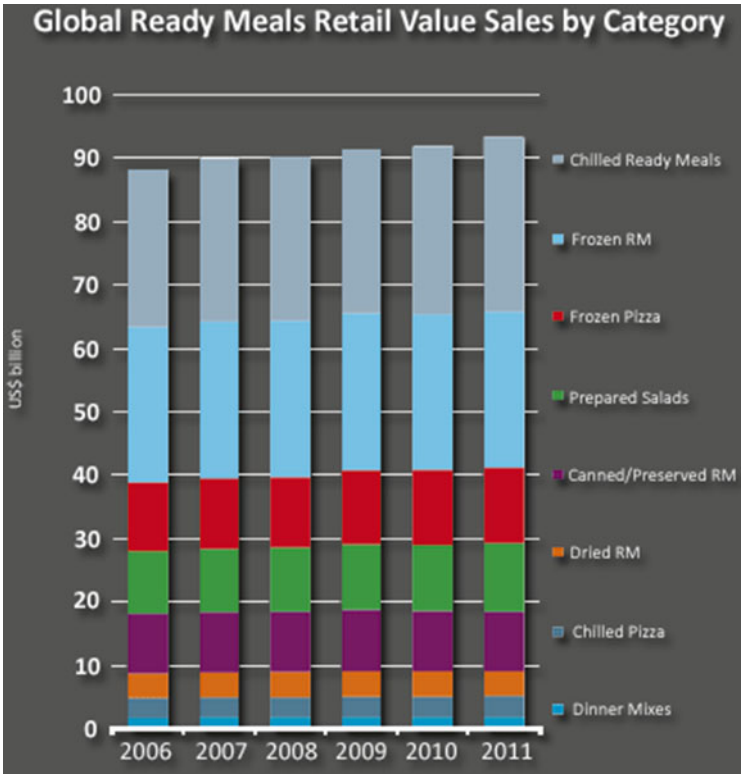

Fig. 6.1 Global ready meals retail value sales by category (Euromonitor International 2013)

supreme secured an established market and others are available in dual cans with cooked rice in another compartment to make a complete meal. As shown in Fig. 6.1, there are clear advantages of these ready meals for their distribution. A number of complete Italian dishes are available in the market (James and James 2005; Euromonitor 2013).

Chilled food can be processed in two ways: super-chilling and freeze-chilling. Super-chilling is a technology used to prolong the shelf-life of food products by cooling and these products are distributed at a temperature of 1–2 °C below their initial freezing point. During super-chilling, only some of the water in the product is frozen. Super-chilling gives a considerably prolonged shelf-life of many fish products as compared to the conventional chilled storage. The freeze-chilling approach implies a conventional freezing of the products and distributed through the frozen chain. On demand, the frozen products are thawed under controlled conditions at +5 °C and sold as chilled products. An advantage of freeze-chilling is the ability to release the products into the frozen cold chain according to their orders, thus increases production flexibility. Moreover, the frozen products can be stored until microbiological tests (total viable count, *Enterobacteriaceae*, *Coliforms*,

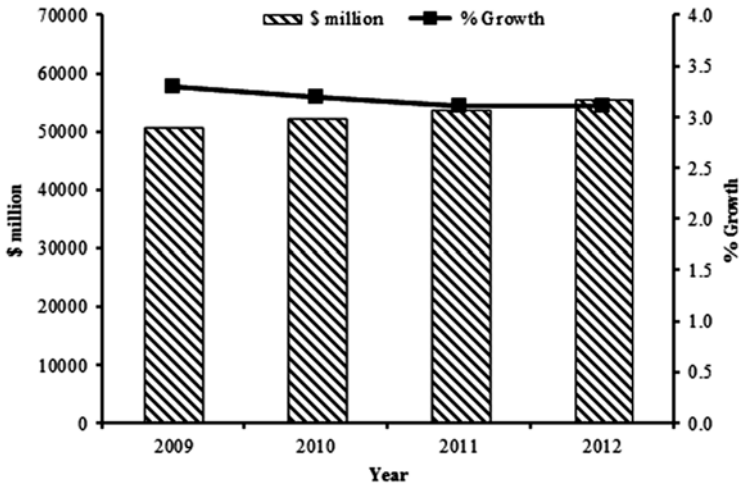

Fig. 6.2 The annual global ready meals market value and growth rate from 2009 to 2012 (Datamonitor 2013)

E. coli, *Enterococci*, *Staphylococcus aureus*, *Bacillus* spp., *Clostridium perfringens*, Lactic Acid Bacteria, *Pseudomonas* spp., yeasts, moulds and other pathogens) are determined. This could reduce the probability of a product recall (Adler-Nissena et al. 2013).

Frozen foods are stored at its freezing condition or at room temperature after freeze drying. Freeze drying is primarily a method of food preservation and it occurs as a result of sublimation of ice to water vapor. The advantage of drying over freezing is development of dried shelf stable product and thus it generally requires only a sealed container to keep it for months or even years at ambient temperature (Stapley 2008).

6.2 Market Trends of Ready Meals

6.2.1 World Market

The ready meals market consists of the retail sale of chilled, dried, canned and frozen ready meals (Fig. 6.1). The market is valued according to the retail selling price (RSP) and includes any applicable taxes. The global market consists of North America, South America, Western Europe, Eastern Europe MEA, and Asia-Pacific. The global ready meals market has produced moderate growth in recent years, with the market expected to grow up to 2017 (i.e. the forecasted period used). The global ready meals market revenue was $55,510 million in 2012 (Fig. 6.2) and it represented a compound annual growth rate (CAGR) of 3.2 % between 2008 and 2012. In comparison, the European and Asia-Pacific markets grew with CAGRs of 4 %

and 3.9 % respectively, over the same period. It reached respective values of $22,798 million from $11,282 million in 2012. Market volumes increased with a CAGR of 2 % between 2008 and 2012, to reach a total of 7,984.1 million kg in 2012. The market's volume is expected to rise to 8,697 million kg by the end of 2017, representing a CAGR of 1.7 % for the 2012–2017 periods (Datamonitor 2013).

6.2.2 Consumer Acceptability of Ready Meals

Convenience foods are receiving popularity and these are developed by fully or partially prepared foods, which need less preparation time, no culinary skills or energy requirement. Convenience is also important as taste and nutrients as well as price. However, convenience foods are commonly associated with less healthy, and these may cause, obesity and chronic diseases, such as cardiac, diabetes and cancer (Jabs and Devine 2006; Celnik et al. 2012).

Behavioral and psychosocial models are required, together with physical and biological measures, to explore why consumers consider 'convenience' so high (Mahon et al. 2006). People recognize convenience in acquiring, storage and preparation of foods and they believe that these products could save time for them (Costa et al. 2007). The perceived benefits include: reduction of stress for meal preparation (i.e. relaxed lifestyle), and easy of hosting social events. The perceived time-scarcity (i.e. convenience) may trade-offs against healthy and taste meals. Lack of skills or dislike of cooking, cost of preparing time and varied family eating times encourage for ready-meals. The notion of marketing ready-meals may actually promote the concept of time-scarcity resonates with the concept of a food-related lifestyle (Celnik et al. 2012). A global survey by Nielsen (2006) over 22,000 internet users around the world (41 countries) has confirmed that the 'convenience' is the main reason for selecting ready-to-eat meals. With less time on their hands to prepare meals from scratch, 83 % of the world's consumers are in agreement that ready-to-eat (RTE) meals come in handy when there is no time to prepare a meal from scratch (Fig. 6.3).

Ready meals are facing competitions in the market. Across the globe, 65 % of the world's Internet users purchase RTE meals either frequently (20 %) or occasionally (45 %) (Fig. 6.3). Across Asia, it is a common practice for people to purchase a pre-prepared meal, in full or part, on their way home from work. This is then reheated at home and consumed. The trends of the range and availability of RTE will continue to grow. The RTE sector is the fastest growing categories. In Hong Kong, for example, in the year 2005 the sales volume of frozen ready meals and frozen dim sum grew 17 % as compared to the previous year. Similarly in Japan, sales volume of microwave instant foods grew 7 % in the year 2005 as compared to the previous year. Figure 6.4 shows the global statistics on the frequency of the purchase of RTE meals by consumers (Nielsen 2006).

Few studies have reported on the acceptability of ready meals. Muktawat et al. (2013) reported that the majority of single male and female used different types of

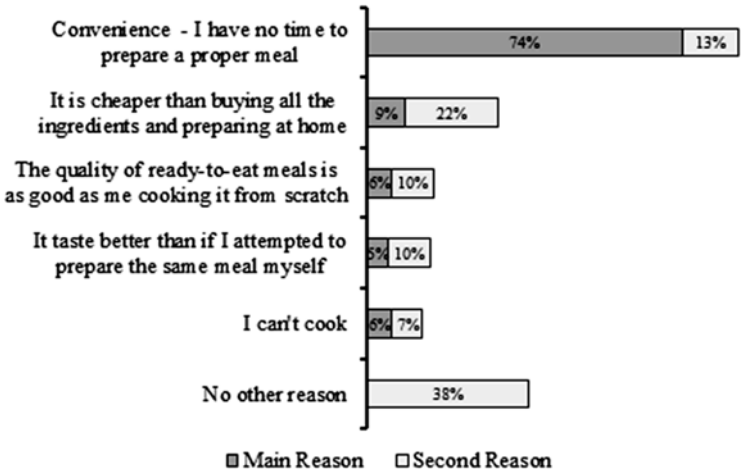

Fig. 6.3 Global average statistics of respondents reason who purchase ready-to-eat meals (Nielsen 2006)

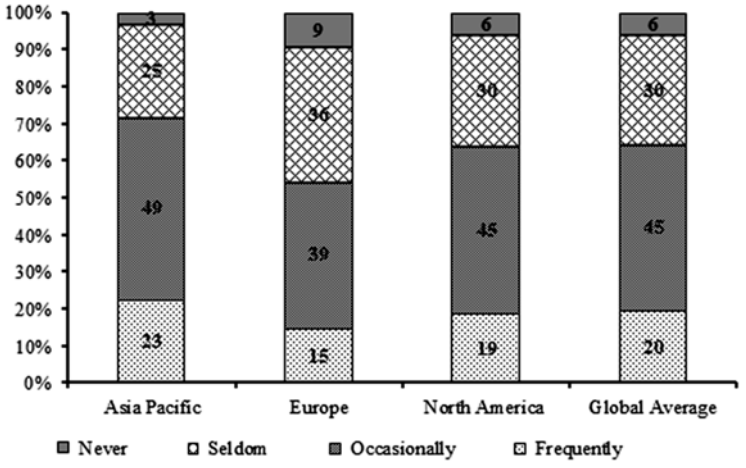

Fig. 6.4 Statistics of respondent purchase ready-to-eat meals (Nielsen 2006)

ready-to-eat food. Sorenson et al. (2011) has reported on the consumer acceptance of high pressure processed (HPP) beef-based chilled ready meals manufactured from a low-value beef cut. Three hundred consumers evaluated the chilled ready meals prepared by four pressure treatments (200, 300, 400, 500 MPa) and they chose a pressure treatment of 200 MPa based on 9-point scale. The attributes considered was beef tenderness and juiciness, overall flavor, overall liking, and intention of purchase. Similarly, Rao et al. (1992) studied the acceptability of ready to

eat foods in four rural areas in India (Korremal, Pratapa Singaram, Katchavani Singaram, Parvatapur). Acceptability trials with the three types of recipes (sweet ready mix, sweet ready mix with amylose and therapeutic food) were carried out on 184 young preschoolers (6 months to 35 months). The therapeutic food was more acceptable (i.e. considering taste, smell and bulk) to the children. In this study, the criteria for acceptability of the food was defined as the ability of 75 % of the children to consume 75 % or more of the food supplement at one sitting. The therapeutic food, a calorie dense supplement, met these criteria. However, the acceptability was poor for the sweet ready mix and sweet ready mix with amylase (<4 %). This was mainly due to quantity rather than taste and smell as revealed by the mothers. The mothers of the children also liked the taste and smell of the therapeutic food. Conversely, the consumption of the therapeutic food caused minimal side effects like diarrhea and vomiting in relation to the sweet ready mix and sweet ready mix with amylase in children.

Olsen et al. (2010) studied the influence of moral attitude on consumers' intention to consume ready meals. In this study, they investigated the usefulness of integrating moral attitude into the Theory of Planned Behavior (TPB) model for the prediction of consumers' intention to consume ready-to-eat (RTE) meals in Norway, Netherlands and Finland. The analyses showed that moral attitude is an important predictor of RTE-meal consumption. The feeling of moral obligation, operationalized as a negative feeling of guilt, had a negative effect on peoples' intention to consume ready meals in all the three countries. The explained variance (R^2) for TPB increased when moral was added as an explanatory factor. According to Costa et al. (2007), moral attitude towards saving time and energy in food preparation may play a considerable role in the consumption of ready meals. Results from their study showed that the replacement of homemade meals by ready meals was influenced by moral-based criticism. While homemade cooking was positively evaluated, buying ready meals was associated with the feelings of guilt, regret, and neglecting one's duty (Byrne 1998; Bowers 2000). The derived conviction came to provide an appropriate amount of effort, attention, and time in meal preparation. Mahon et al. (2006) also studied the theory of planned behavior to examine the consumption of the ready meals and purchase of take-away food by British consumers. They claimed that the food products attitudes were the best predictor for determining the behavioral intention. For both food products (ready meals or take-aways), behavioral intentions, perceived behavioral control, and habit are important predictors. In a separate analysis, value for money was the most important of three beliefs investigated. Beliefs differed significantly between the two groups with intenders having positive beliefs about the convenience products (Mahon et al. 2006).

Consumers' acceptability of ready meals is primarily influenced by considerations, such as taste, cost, convenience, and nutritional value of foods. Food pricing and marketing practices are essential components of the eating environment. Price reduction strategies promote the choice of targeted foods by lowering their cost relative to alternative food choices. It is reported the reduction on price in foods will attract consumer to purchase as well as increase the sales (Traub and Odland 1979; Simone 2003).

6.3 Nutritional Value of Ready Meals

Nutrient-profiling has been proposed as a tool for health promotion (Lobstein and Davies 2009) but categorizing individual food as 'healthy' or 'unhealthy' is misleading. Foods are consumed in meals and snacks, which comprise the overall diet. The quantities of nutrients in foods are diversified (Verhagen and van den Berg 2008; Celnik et al. 2012). The appropriate energy content is essential before other nutrients are considered. Ready meals are often rich in energy, fat, sugar, and vegetables. van der Horst et al. (2010) reported that men are being more positive about ready meals since they usually possessed lower cooking skills as compared to women. Overweight adults (BMI: 25 kg/m^2) were more positive about nutrients and vitamins in ready meals as compared with normal-weight adults.

Ready-meal consumption was associated with cooking skills, age, overweight, nutritional value, taste, working status, and gender (van der Horst et al. 2010; Olsen et al. 2010; Geeroms et al. 2008). Another nutritional study on ready meal's consumption was reported by Lichton et al. (1988). A new military operational ration were fed ready-to-eat meals to army during a 34-days field exercise and it was observed that they experienced significant weight loss as compared to those fed hot meals. Neither group appeared to be dehydrated. Hemoglobin and hematocrit values showed elevation. Both groups of soldiers displayed acceptable nutritional status, serum proteins, vitamins, and Zn. Jago (2000) found a negative effect of the belief of physical health on the purchase of convenience foods. Ready-meals are related to obesity and other ill-health due to inadequate nutritional contents of ready meals (van der Horst et al. 2010 and Celnik et al. 2012).

The average ready meals contain 1,200 kcal. When consumed three times daily, the average person's caloric intake is 3,600 kcal/day. This intake is appropriate in temperate environments (requiring 3,250 kcal/day) but must be increased to four meals daily to meet cold weather environments (requiring 4,500 kcal/day). The caloric supplement snack packs were developed to meet these increased requirements (Edwards and Roberts 1991).

6.4 Quality and Safety Issues of Ready Meals

Consumers are becoming aware of the safety and quality of food products. Interest grows as new food products are introduced onto the market and modern technologies are being used (bakery products, frozen ready-to-eat meals, organic and others special foods). The evaluation of a food product needs the identification of several quality factors, such as appearance, flavor, nutrients contents, texture, and

microbiological quality (Kindt et al. 2008). The principal mechanisms involved in the deterioration of processed foods are as follows:

1. Microbiological spoilage sometimes accompanied with pathogen,
2. Chemical and enzymatic activity caused lipid breakdown, color, odor, flavor, and textural changes,
3. Moisture and/or other vapor migration caused changes in texture, water activity and flavor.

6.4.1 Relationship Between Shelf Life and Microbiological Aspects of Ready Meals

The production process of ready meals is generally located in geographical areas having logistical efficiencies in their distribution. This is due to the high intrinsic value and cost of preparation, and to maximize the shelf-life with shortened chill transport and storage chain. Due to their complexity and the high level of manipulation involved in their preparation caused more prone to spoilage as compared to their constituent ingredients alone. Therefore, potential microbial growth (i.e. safety) and relatively short shelf life are paramount for the success and sales of these products (Spencer 2005).

The shelf life of these products is affected by their microbiological status. These products pose the highest food safety risk and possessed the shortest shelf life due to easy microbiological deterioration. Bacteria need certain conditions for their growth, such as moisture, pH, temperature and nutrients. By controlling these conditions, one can prevent the growth of these organisms in ready meals and extend their shelf life (Labuza and Hyman 1998; Mathlouthi 2001). Once the product is developed utilizing a combination of the proper ingredients, pH, water activity, and microbiological inhibitors, its shelf life can be determined in real time at the various temperatures during their storage and distribution (Min et al. 2013). The growth of yeasts, molds, spoilage, and pathogenic bacteria can be monitored during storage time. Other noticeable reactions, such as gas production, syneresis (phase separation), and changes in color or viscosity can give further indications on the proper formulation and packaging (Khairudin and Muhamad 2013). In addition challenge test could be performed by adding various spoilage organisms as well as selected potentially pathogenic bacteria to ensuring an adequate shelf life (Labuza 1982). *Listeria monocytogenes* grows under refrigerated conditions. It is imperative that must not be present in refrigerated products. Microbiological shelf-life can usually be predicted quite accurate (Labuza 1982). Water are involved in most food product deterioration. Microbial growth, enzyme activity, non-enzymatic browning, and textural changes are affected by moisture (Labuza 1970). The effects of water activity on relative reaction rates for these mechanisms of deterioration are illustrated in Fig. 6.5 (Rahman 2009).

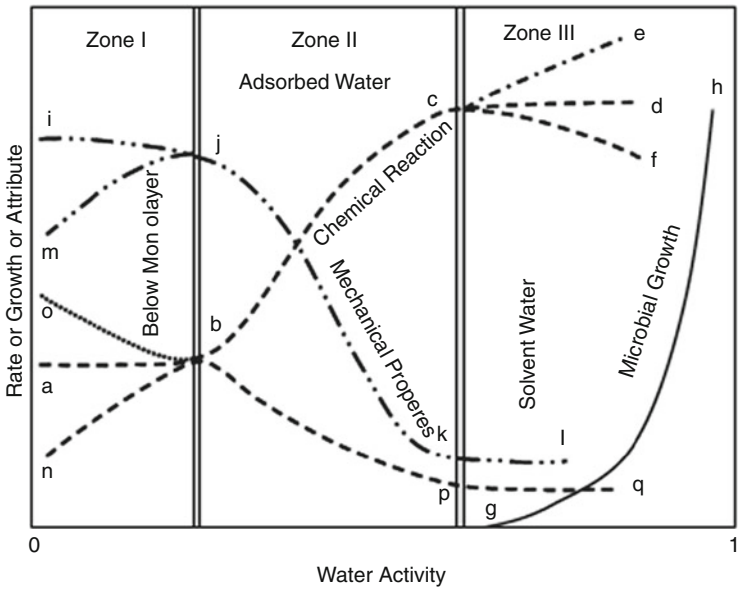

Fig. 6.5 Updated stability diagram based on the water activity concepts (Rahman 2009)

Clarence et al. (2009) studied the bacteriological quality of ready to eat meal (meat pie) by analyzing *Staphylococcus aureus* and *Escherichia coli* in the meat pie. The mean microbial load on the fresh meat pie ranged from 3×10^3–5×10^3 CFU/g, while the microbial load in refrigerated meat pie ranged within 8×10^3–1.5×10^4 CFU/g after storage 2 days. The mean microbial load of the fresh meat pie from the local kiosk ranged within 7×10^3–2.8×10^4 CFU/g. The air preserved and refrigerated meat pie for 2 days ranged between 3×10^{-4} to too numerous to count (TNTC) and 1.3×10^4–2.8×10^4 CFU/g, respectively. Jung et al. (2013) quantitatively analyzed the staphylococcal enterotoxins (SEs) produced by *Staphylococcus aureus* in contaminated ready-to-eat kimbabs and sandwiches stored at 17–30 °C. The amount of SE in the kimbab was positively correlated with the growth of *S. aureus* at all storage temperatures except 17 °C. The maximum amount of SE in the sandwich did not exceed 0.5 ng/g regardless of storage temperature. The maximum amounts of SE in the kimbabs and sandwiches were 1.8 ng/g and 0.15 ng/g after 30.5 and 52 h at 30 °C, respectively. This indicated that SE production was dependent on the types of food matrix. In addition, the thermal inactivation of staphylococcal enterotoxin D (SED) producing *S. aureus* in the kimbabs and broth was determined at temperatures 51–63 °C. Significant differences in the D-values between the kimbab and broth were observed at 51–63 °C, but the z-value was not significantly affected by the model media.

Kotzekidou (2013) performed microbiological examination of ready-to-eat foods and ready-to-bake frozen pastries from 15 university canteens during a 10-year

inspection survey (2001–2010). The cumulative study revealed that the aerobic colony counts for the RTE product groups were as follows: from 106 to 108 CFU/g for 50 % of sandwiches; under the detection limit (<10 CFU/g) for 88.6 % of oven baked pastries; $<10^5$ CFU/g for 86.5 % of desserts oven baked; from 10^3 to 10^9 CFU/g for desserts with dairy cream. The highest mean *Enterobacteriaceae* counts were recorded for desserts with dairy cream. The highest percentages of foodborne pathogens were: *Listeria monocytogenes* (20 %) and *Staphylococcus aureus* (12.5 %) in desserts with dairy cream; *Salmonella* spp. (17.5 %) and presumptive *Escherichia coli* O157 (8.5 %) in sandwiches and *Bacillus cereus* (14.6 %) in oven baked pastries. Aerobic colony counts were in the range of 10^7–10^8 CFU/g for 48.8 % of frozen pastries; whereas *Enterobacteriaceae* counts between 10^3 and 10^4 CFU/g were detected in 35.3 %. Foodborne pathogens prevalence for frozen pastries were as follows: *B. cereus* (31.8 %), *Salmonella* spp. (28.6 %), presumptive *E. coli* O157 (25 %), *S. aureus* (8.7 %) and *L. monocytogenes* (8.7 %).

A bacteriological assessment of the food products at different stages of processing was conducted during the manufacturing of ready-to-eat (RTE) chicken franks, chicken bologna, and bacon at a large meat processing plant in Trinidad, West Indies. *Staphylococcus aureus* was the most common pathogen detected in precooked products (mean counts 0.66, 1.98, and 1.95 log10 CFU/g for franks, bologna, and bacon, respectively). This pathogen was also found unacceptable levels in 4 (16.7 %) of 24 post-cooked samples. Fifty percent (10 of 20) of precooked mixtures of bacon and bologna were contaminated with *Listeria* spp., including four with *L. monocytogenes*. Pre-cooked mixtures of franks and bologna also contained *E. coli* (35 and 0.72 log10 CFU/g, respectively) while 5 (12.5 %) of 40 pre-cooked mixtures of chicken franks had *Salmonella* spp. Aerobic bacteria exceeded acceptable international standards in 46 (82.1 %) of 56 pre-cooked and 6 (16.7 %) of 36 post-cooked samples. Both pre- and post-cooking air and processing surfaces had relatively high levels of aerobic bacteria, *Staphylococcus aureus* and coliforms, including equipment and gloves of employees. A drastic decrease in aerobic counts and *Staphylococcus aureus* levels was observed after heat treatment, thus subsequent increase suggests that there is a post-cooking contamination. A relatively high level of microbial contamination risk exists for RTE meats at the processing plants (Syne et al. 2013).

Irawati et al. (2007) investigated the effect of irradiation at medium doses in combination with cryogenic condition to ensure the safety, quality and shelf-life of prepared meals. Semi-concentrated black, ox-tail, chicken vegetable and chicken sweet corn soups were individually packed in a dry laminate pouch of PET 12 μ/LDPE and 2 μ/Al–foil 7 μ/LDPE adh/LLDPE (C_4) 50 μ. The product under vacuum packed was subjected to freezing for 24 h at −18 °C prior to irradiation doses of 1, 3, 5 and 7 kGy at cryogenic condition (−79 °C), respectively. Both the non-irradiated and irradiated meals were then stored in refrigerator at 5 ± 2 °C. Non-irradiated and irradiated samples at 1 kGy were mostly spoiled after a week of storage. Gamma irradiation at doses of 5–7 kGy for the soups could reduce microbial load by 2–3 log cycles, without affecting the physico–chemical parameters and palatability. The storage life of irradiated product was 2–3 months, while the un-irradiated samples could store only for 1 month.

6.4.2 Storage and Packaging of Ready Meals

In recent years, there has been an increased demand of processed convenient foods, particularly in the Armed Forces. Such foods should provide energy and other nutrients in the required proportions to promote health and nutrition of the army personnel. Namratha et al. (2002) evaluated the effect of storage on the resistant starch (RS) content of selected ready-to-eat (RTE) foods, viz., vegetable kichidi, vegetable pulav, chicken pulav, mutton pulav, sooji halwa, upma, cauliflower peas curry and potato peas curry prepared by Defense Food Research Laboratory (DFRL). Resistant starch was quantified directly in the residues obtained after removing digested starch in simulated physiological conditions. Nutrient content and carbohydrate profile of the foods were also analyzed. Nutrient content varied depending on the basic ingredients used in their preparation. Total starch ranged from 18 to 74 % and dietary fibre 13–20 %, respectively. Storage of 4 months resulted in a significant increase ($P<0.05$) in the RS content of all foods except mutton pulav. It appeared that storage time is an important factor for RS formation in RTE foods in addition to their processing methods (Namratha et al. 2002). Other study on the effect of storage on resistant starch and amylose content of cereal–pulse based ready-to-eat was reported by Kumari et al. (2007). A wide range of ready-to-eat (RTE) foods with varied shelf life is commercially available for the Armed Forces and the public at large. The above study evaluated the effect of storage on the resistant starch (RS) and amylose content of selected ready-to-eat (RTE) cereal–pulse processed foods viz., pongal, khara bhath, dal fry, bisibele bhath, rajmah and kesari bhath, developed by Defence Food Research Laboratory, Mysore. RS was quantified directly in the residues obtained after removing digested starch in simulated physiological conditions. Nutrient composition and carbohydrate profile of the foods were also analyzed. The carbohydrate profile indicated a low amount of sugars, except in the case of kesari bhath. The total starch content ranged from 14.5 to 24 % while amylose ranged from 1.2 to 7.2 %, respectively. The total and resistant starch in the RTE foods varied depending on the ingredients used and type of processing. Foods containing higher amylose content were found to have maximum increase in RS content after storage. Storage at ambient condition resulted in significant increase ($p<0.05$) in RS and TS content of RTE foods. The findings revealed that the RTE foods contained appreciable quantities of RS and the amount was further increased upon storage.

RTE pasta meals are becoming an important segment of the global food market. Ready to eat pasta meals are subjected to quality loss and, in particular, textural degradation during storage. The complexity of these products [e.g. presence of multiple phases (pasta and sauce), high moisture content], makes a challenge for the food industry to understand the phenomena involved in their aging process. Carini et al. (2014) published the first scientific report by describing and comprehending the phenomena involved in the aging process of RTE pasta meals. The changes in physico-chemical properties of RTE shelf stable pasta during storage were investigated with a multi-analytical and multidimensional approach (with special focus on water status) to understand the ageing process. Pasta hardness and amylopectin re-crystallization increased. The macroscopic water and proton molecular

translational mobility remained constant, while significant increase in the proton rotational molecular mobility was observed during storage. Since the main changes observed in RTE pasta during storage were similar to those observed in other cereal-based products, it would be interesting to verify the effect of the anti-staling methods commonly used in the cereal processing industry (Carini et al. 2013, 2014).

Pourashouri et al. (2013) addressed the quality loss in two different ready-to-eat (RTE) seafoods. The chemical and microbiological parameters were measured in tuna lasagne (TL) and hake roe foods, which were refrigerated (4 °C) for up to 35 and 71 days, respectively. Both foods showed a significant lipid oxidation (peroxide and interaction compound formation) during storage time, which was especially marked in the case of the TL product, which also underwent an important lipid hydrolysis development. Both RTE products showed a low microbial development, no matter how much time had elapsed since the expiration dates; thus, low total viable count scores and volatile amine formation were attained while the presence of pathogen microorganisms was not detected. In view of the current increasing consumer demand for high quality refrigerated foods, the assessment of lipid damage related to nutritional and sensory values is recommended when fish-based RTE products are encountered.

Edible antimicrobial films were prepared using coating solutions incorporating chitosan, lauric arginate ester (LAE) and nisin by Guo et al. (2014) to reduce foodborne pathogen contamination on ready-to-eat (RTE) meats. The antimicrobial efficacy of the coatings and films against *Listeria innocua* (*L. innocua*) inoculated onto the surface of RTE meat samples was investigated. Antimicrobial coatings with 1.94 mg/cm^2 of chitosan and 0.388 mg/cm^2 of LAE reduced *L. innocua* by ca. 4.5 log CFU/cm^2. Nisin (486 IU/cm^2) showed less effectiveness than LAE (0.388 mg/cm^2) and addition of nisin to the antimicrobial coatings or films containing LAE (0.388 mg/cm^2) did not enhance the total antimicrobial effectiveness (Fig. 6.6). Combining antimicrobial coatings or films with flash pasteurization (FP), which uses short burst of steam under pressure, has further reduced *L. innocua*, achieving over a 5 log reduction. There was no significant difference in the effectiveness of antimicrobial films versus the coatings ($p > 0.05$). These data show the potential use of antimicrobial packaging alone, or in combination with FP, in preventing foodborne illness due to postprocessing contamination of RTE meat products (Guo et al. 2014).

Another studies by Sung et al. (2014) reported the effectiveness of low density polyethylene (LDPE) based film incorporated with garlic oil. These are used to control the inhibition of pathogens in the ready-to-eat beef loaves. The blown film extrusion method was employed to produce this film samples added with garlic oil in 2, 4, 6 and 8 % w/w as well as sample with 0 % w/w, which served as control throughout the study. Besides, several analyses were also conducted to determine the water vapor barrier properties, thermal stability, and bonding interaction of the plastic packaging as influenced by the incorporation of garlic oil. The outcomes of challenge test showed that regardless of the garlic oil amount (2–8 % w/w), the antimicrobial plastic packaging was able to reduce the number of *Listeria monocytogenes* on beef loaves after 3, 6, 9 and 15 days of storage at 4 °C. However, there were insignificant effects on both *Escherichia coli* and *Brochothrix thermosphacta*.

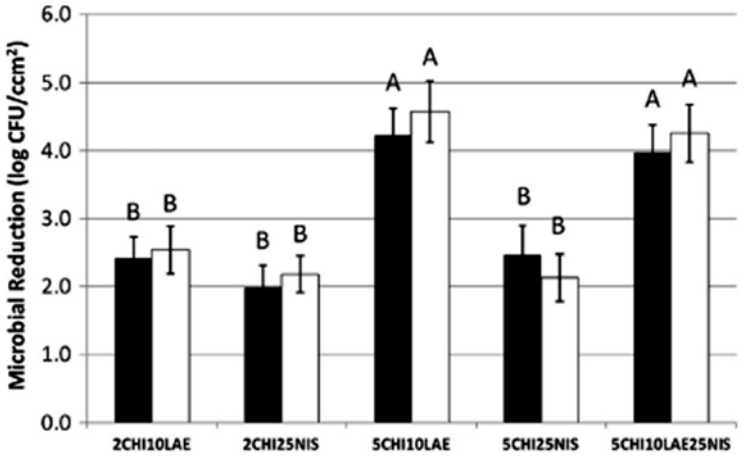

Fig. 6.6 Reduction of *L. innocua* on meat surfaces treated by antimicrobial coatings and films containing chitosan, LAE and nisin. 2CHI10LAE: 0.389 mg/cm^2 of chitosan and 0.388 mg/cm^2 of LAE; 2CHI25NIS: 0.389 mg/cm^2 chitosan + 486 IU/cm^2; 5CHI10LAE: 1.94 mg/cm^2 chitosan + 0.388 mg/cm^2 LAE; 5CHI25NIS: 1.94 mg/cm^2 chitosan + 486 IU/cm^2 nisin; 5CHI10LAE25NIS: 1.94 mg/cm^2 chitosan + 0.388 mg/cm^2 LAE þ 486 IU/cm^2 nisin (Guo et al. 2014)

6.5 Health Issues on Ready Meals Consumption

According to Chen (2013), the trends of ready meals can be categorized into three main streams (1) Healthy: products are marked as organic, locally produced, vegetarian products, (2) Convenience: ready meals are sold in convenience stores, which are also providing space for dining similar to restaurants. (3) Wide Varations: new flavors, exotic cuisine, consumers' selection (i.e. consumers can select their ingredients), ethnic foods, and foods for elderly.

The current obesity epidemic has been linked to excessive consumption of added sugars and fat in addition to the sedentary lifestyles. Fat and sugar provide dietary energy at very low cost (Simone 2003). Food intervention is a financially sensible way for prevention and treatment of diabetes. Extruded snack foods are considered as high glycemic products. Brennan et al. (2012) studied the impact of dietary fiber-enriched ready-to-eat extruded snacks on the postprandial glycemic response of non-diabetic patients. They reported that oat bran inclusion reduced *in vitro* starch digestibility but not *in vivo* glycemic response. The inclusion of oat bran into the snack products appeared to extend the glycemic response of individuals compared to the control snack. This suggests that there is a possibility of prolonging glucose release and potential effects on satiety responses. The positive effect in attenuating glucose response means that psyllium fiber could be a target for inclusion by the snack food industry to effectively manipulate postprandial glucose response.

Promoting folate intake from natural food sources is a healthy strategy for attaining safe levels of folate. This could avoid potential harm from chronic excessive intakes of folic acid from fortified food products or supplements. Over recent years, the consumption of ready-to-eat foods, such as packed vegetables or precooked meals, has become a significant part of the diet. Accordingly, the folate composition of these food categories must be investigated. There is a broad lack of folate data in food composition tables and databases, especially for ready-to-eat products. This context warrants the need of new data on total folate and individual forms of folate in ready-to-eat commercial products. This could be included in the food composition tables or databases to assess its dietary intakes. Currently, the recommended intake of folate in some European countries ranged from 400 to 500 mg/day for women of childbearing age, 600 mg/day for the second half of pregnancy and 500 mg/day for breastfeeding women. For other population groups, the recommended daily intakes (RDI) for folate are established depending on the age and sex of the individuals (children around 150–200 mg/day, and adults and elderly, 300–400 mg/day), the limits vary considerably among European countries. The challenges to improve the folate data in food composition databases exist in most developed countries (Fajardo et al. 2012).

Olsen et al. (2012) developed a new concept of a complete and healthy ready-to-heat (RTH) meal and tested it in at-home study in Norway. Since previous at-home testing of meals has been conducted on products like soup and lasagne, they adapted a new procedure for at-home testing of more complex meals. The results indicated that the likelihood of buying healthy convenience food is first affected by overall liking of the meal, which is affected by sensory liking, such as appearance, flavor and odor. The liking depends on the socio-demography of the consumers. Gender, age, education and overall liking influence consumers' likelihood of buying the salmon meal, while no significant socio-demographic drivers were found for the chicken meal. There is little published specifically on the relationship between ready-meals and obesity. However a Brazilian study on almost 50,000 subjects found significant correlations between obesity in women and intakes of sugar and soft drinks, ready-to-eat meals, and potatoes. Food-choice depends on balancing advantages, availability, accessibility, attractiveness, and affordability (Celnik et al. 2012).

6.6 Conclusions

Modern lifestyle has increased demand for the ready meals in the form of nutritious snacks and convenience foods, ethnic dishes and other specialty products. This chapter has presented a brief overview on the ready-meal in terms of its definitions, types and importance. It illustrates the convenience of ready-meal and how it affects consumers' modern lifestyle. The nutritional aspects of ready meals consumption is related to different health issues. In relation to ready meals, most on-going researches are focusing on the ways to improve the efficiency and performance of the production process. These areas include the chilling, freezing and packaging of the products.

The quality of the ready meals depends on the shelf life and acceptance of the product. The product development of ready meals is generally oriented towards market demand (i.e. consumers' preferences), thus consumers' perspective is the most crucial aspect in developing ready meals and its future progress.

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Chapter 7
Processing, Storage and Quality of Cook-Chill or Cook-Freeze Foods

Atef Elansari and Alaa El-Din A. Bekhit

7.1 Introduction

Over the history of mankind, food preservation has played a crucial role in alleviating hunger and famine when food was less abundant and was instrumental in supplying edible foods for armies, voyagers and explorations that led to significant changes in human history. Progress in food preservation and processing can be considered as four main processing paradigm shifts over human history: (1) production of safe foods (early human trials–1950s); (2) production of safe food that have desirable sensory properties, i.e. looks good and tastes good, (1960s–1980s); (3) production of safe high quality food that is nutritionally sound (1990s–2000s); and 4) production of safe nutritious high quality food that delivers specific functions (2000s–present). Hence, the food industry moved from primitive concepts, such as simple dehydrated products and cured foods, to technologies such as canning, refrigeration and freezing. The purpose was to meet the demands for healthy and nutritious safe foods.

The increased demand for ready to eat fast meals prepared by food catering sectors outside the home during the 1960s highlighted the value of cooked-chilled and cooked-frozen foods. Significant interest in the 1960s and 1970s resulted in implementation of the technology at the commercial or industrial scale. The interest in technology development decreased during the 1970s and the 1980s due to high production costs associated with cost of electricity, labour and the capital cost of equipment. Total food expenditure on the meals prepared outside the home was

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reported to increase about twofold in the US during the 1990s (Manchester and Clauson 1994). This trend of expenditure as well as other demographic changes in working hours and increased participation of women in the labour force (Jekanowski et al. 2001), increased the value of convenience (Hiemstra and Kim 1995) and promoted the availability of more energy-efficient processing systems (Light and Walker 1990), which revived interest in cook-chill and cook-frozen technologies in the food industry.

7.2 Cook-Chill and Cook-Freeze Systems

A cook-chill system is a preservation technology where food (raw material and other ingredients) is fully cooked at usually <100 °C and the product is subsequently chilled rapidly and stored under controlled conditions where the final core temperature is maintained above the freezing point at 0–3 °C and can produce an extended shelf life at 4–10 °C (Evans et al. 1996; Sun and Hu 2002). The use of high quality raw material is an essential requirement to guarantee high quality products. The destruction and inhibition of microorganisms, especially the pathogenic ones, are achieved through the initial cooking step and subsequent storage at lower temperatures (Hill 1994). The general cook-chill process in Denmark, France, Germany, Sweden and the UK requires a thermal treatment in the range of 65–80 °C followed by a chilling process to achieve a temperature of 10–3 °C within 1.5–4 h and then stored at a temperature within 0–3 °C (Hill 1994). More recently "supercooling conditions" are being used to extend the shelf-life of the products by maintaining their temperature at 1–2 °C below freezing temperature.

The cook-chill process is also conducted under vacuum (referred to as 'sous-vide'; Fig. 7.1). In this process, food is vacuum packed inside a heat-stable pouch or tray before cooking (Nyati 2000). Sous-vide products are normally cooked at a temperature of less than 80 °C and a shelf-life of up to 28 days is usually achieved (Tansey et al. 2010). The extended shelf life is limited to 28 days due to the potential of toxin production by non-proteolytic strains of *Clostridium botulinum* at 3.3 °C within 31 days (Schmidt et al. 1961). The vacuum bag barrier between the cooked product and the environment protects the product from potential post-cooking contamination.

Cook-freeze food products are treated the same way as cook-chill products, but the final product is either super-chilled (i.e. cooled and maintained at 1–2 °C below the freezing temperature of the product) or frozen-chilled (i.e. frozen at a temperature of below −30 °C and then thawed to 5 °C when needed (O'Leary et al. 2000; Redmond et al. 2004). This allows 'chilled' foods' delivery to more distant markets, facilitates bulk production, and reduces the level of product recalls. The main limitation of the shelf life of cook-chill and sous-vide processed products are the degradation of sensory attributes and microbial growth. These attributes depend on

Fig. 7.1 Examples of some commercial cook-chill and sous-vide products

the storage conditions (time and temperature). Diaz et al. (2008) investigated the spoilage over 10 weeks of sous-vide pork loin at chilled condition (i.e. cooked at 70 °C for 12 h, and then chilled at 3 °C) by examining microbial, physicochemical and sensory attributes. Their results demonstrated that sensory spoilage occurred prior to microbial spoilage and the pork was unacceptable after 10 weeks of storage based on its sensory properties. Thus this method provides extended protection against microbial concerns.

The shelf-life of cook-freeze products is limited by structural changes in the food (i.e. ice crystal size and off flavour formation). This is due to the production of chemicals, such as formaldehyde and free fatty acids by hydrolysis and oxidation. The shelf life of cook-freeze products is dependent on the chemical composition of the food, packaging system and storage conditions (i.e. time and temperature). Foods processed using the above technologies are collectively known as refrigerated processed foods (REPFED; Rajkovic et al. 2010).

Several recommendations have been adopted in regulations and guidelines for the production of cook-chill and sous-vide food products include: US Food Code 2003 in 3-502.11.D and 3-502.12, (with additional information in Annex 3, 4 and 6) http://www.fda.gov/downloads/Food/GuidanceRegulation/RetailFoodProtection/FoodCode/UCM374510.pdf; European Chilled Food Federation recommendations http://www.ecff.net/images/ECFF_Recommendations_2nd_ed_18_12_06.pdf; Food safety authority of Ireland recommendations www.fsai.ie/WorkArea/DownloadAsset.aspx?id=746; NSW Food authority Australia http://www.foodauthority.nsw.gov.au/_Documents/industry_pdf/guidelines_vp_2011.pdf, UK http://www.food.gov.uk/multimedia/pdfs/csctcooking.pdf.

7.3 Microbiological Considerations

The processing associated with REPFED (Table 7.1) is based on the requirement of a 6 log reduction of *L. monocytogenes* and *C. botulinum*. This is regarded as a "worst case scenario" in chilled products (Rybka 2000; Rybka et al. 2001). The products are processed at a temperature range of 65–100 °C for different times. Maintaining the center of a product at 60 °C for 45 min, 65 °C for 10 min or at 70 °C for 2 min can deliver the same lethality value (Rajkovic et al. 2010). Even lower temperatures with longer treatment times may be acceptable (the 'thermal death concept'). The use of lower temperatures may be preferred to maintain the sensory properties of a product or to enable faster cooling, but this can lead to post-processing problems. The raw material and personal hygiene can be a source of unwanted aerobic microorganisms (e.g. *Staphylococcus aureus* and *Bacillus cereus*, respectively) and this can represent a significant health hazard. Thus the importance of good hygiene and a clean production system needs to be emphasized. The use of mild cooking treatments (e.g. pasteurization) in cook-chill products may not be sufficient to inactive pathogenic spores and therefore a low chilling rate during post-cooking may pose a potential problem with spores germinating to vegetative cells. Bacteria can potentially survive mild heat treatment, for examples non-proteolytic *Clostridium botulinum* (Anaerobic, $D_{80°C} = 21.6$ min, $z = 7$ °C,

Table 7.1 Processing requirements and shelf life of cook-chill, sous-vide and cook-freeze products

Process step	Cook-chill	Sous-vide	Cook-freeze
Cooking	≥70 °C <100 °C for >2 min[a]	≥70 °C <100 °C. no time specified	≥70 °C <100 °C for >2 min
Time to cooling	Within 30 min	Immediately	Within 30 min
Cooling rate	To 3 °C within 1.5 h	To 3 °C within 1.5 h	To −5 °C at the centre within 1.5 h
Storage temperature	0–3 °C	0–3 °C or −18 °C	≤−18 °C
Shelf life	5 days at 0–3 °C	8 weeks at −18 °C	8 weeks at −18 °C
	24 h at 5–10 °C	4 weeks at 0–3 °C	
		12 h at 5–10 °C	
Consumptions	Re-heat at 70 °C minimum for not less than 2 min. Consume immediately	Re-heat at 70 °C minimum for not less than 2 min. Consume immediately	Once thawed should be consumed after heating at 70 °C minimum for not less than 2
	Meat joints should not exceed 3 kg or 100 mm thick		

Modified from James and James (2005)

[a]Thermal treatment (70 °C for 2 min or equivalent) is sufficient to ensure a 6 log reduction in numbers of *L. monocytogenes* which is considered the most heat resistant vegetative pathogen (Gaze et al. 1989)

grows at 3 °C), proteolytic *C. botulinum* (Anaerobic, $D_{121.1°C}$ = 0.23–0.3 min, z = 10 °C, grows at >10 °C), *C. perfringens* (Anaerobic, $D_{98°C}$ = 21–31 min, z = 3.8 °C, grows at >15 °C) and *B. cereus* (Aerobic, $D_{100°C}$ = 2.7–3.1 min, z = 6.1 °C, grows at >4 °C) (Baldwin 2012). *Bacillus cereus* is capable of growing at low temperatures but the growth of the bacteria is significantly lowered at 7 °C. These bacteria are considered to be potentially hazardous in the case of inadequately prepared sous-vide products (Rybka et al. 2001), but strict chilling temperature control below 4 °C is reported to control the growth of Bacillus spp. (Carlin et al. 1999). Rapid chilling can control the hazard posed by *C. perfringens* and controlled chilled storage and reheating at >70 °C can control *C. botulinum* (Wilkinson et al. 1991). Some incidences of high total aerobic viable count in cook-chill meals prepared in a hospital (Chudasama et al. 1991) were probably related to inadequate re-heating and cross contamination. The potential problem arises if hazard analysis critical control point (HACCP) plans are not in place. The incorporation of additional safety hurdles [irradiation, modified atmosphere packaging, high pressure, use of chemicals (e.g. lactate, pH and salts) and biological agents (e.g. bacteriocins and protective/probiotic cultures)] can potentially be useful to improve the safety of products. However this may cause side effects on the sensory and nutritional properties of the products (Rybka-Rodgers 2001). Bacteriocins and protective cultures can be more acceptable by consumers compared to other technologies, such as irradiation. This is due to their natural image, wide use in food products such as dairy products, and their role in gut health (Rodgers 2004). The use of protective cultures show many beneficial effects (i.e. potential of decreasing the severity of processing; improving the negative effects of heat on thermo-sensitive compounds/foods, or improving the sensory properties of the food; Rodgers 2003). New developments in microencapsulation or production of cultures with high thermal tolerance may be key for significant use of protective cultures in REPFED. Lactic acid bacteria can survive under the storage conditions of sous-vide and cause spoilage (Carlin et al. 1999). Lactic acid bacteria were isolated from a number of sous-vide products, such as spaghetti and meat sauce, chicken breast meat, chicken mousse and chicken chasseur, fish banding and meatballs (Simpson et al. 1994; Nyati 2000). The low pH of the products was thought to aid bacterial growth, but it was not the case with low pH fish curry (Shakila et al. 2012) or sous-vide fish cake (Shakila et al. 2009).

7.4 Applications of Cook-Chill Processing Systems

Cook-chill systems are used mainly in foods from the catering service industry as well as chilled ready meals from supermarkets. Chill-cook foods are widely available in commercial catering businesses such as hotels, restaurants, and fast food outlets with application in the preparation of large numbers of meals needed to be served in a short time, such as universities, airlines, and the army and for “heat and eat” meals. The technology has proven to be successful since there are few reports of food poisoning or food outbreaks due to the consumption of sous-vide, cook-chill or frozen-chill foods (Peck et al. 2006).

7.5 Advantages and Disadvantages of Cook-Chill and Cook-Freeze Products

Cook-chill technology shows great synergy when it is used with irradiation to inhibit *L. monocytogenes* and *Salmonella typhimurium* (Grant and Patterson 1995). This is due to irradiation-induced damage to the bacteria making them more vulnerable to thermal inactivation. Irradiation of cook-chill roast beef at 0.8 kGy can decrease the thermal *D* and *z* values of bacteria by >50 %. This suggests that *L. monocytogenes* and *S. typhimurium* can be easily killed during the reheating step required before serving cook-chill products. Sous-vide microwaving was found to be one of the best treatments to decrease the microbial counts of psychrophilic and enterobacteria on broccoli (Martínez-Hernández et al. 2013). The integration of the cook-chill system with other quality control systems can produce excellent results. For example, the introduction of a HACCP system in hospitals using a cook-chill system for catering resulted in more than 90 % reduction of microbial load ($<1 \times 10^3$ colony forming units (CFU) per g) and complete elimination of pathogenic bacteria (Shanaghy et al. 1993).

Due to the nature of the food catering industry that requires serving a large number of meals in a timely manner and the convenience of ready to eat chilled meals, cook-chill is a more efficient system to meet these demands compared to the cook-serve operation. Cook-chill and cook-freeze technologies provide several advantages over conventional food processing. These can be summarized as follows:

1. Ability to maintain a pre-stocked inventory that eliminates problems during peak demand and shortage of raw materials' supply.
2. Shelf life extension and ability to supply to distant markets.
3. Ability to reduce labour, raw material and other costs by 20–50 % since the food is prepared in advance.
4. Ability to produce larger quantities, which improves the cost and efficiency of production. Although reports claim up to 50 % reduction in the number of FTEs (Chater 2000), some studies reported little difference among conventional-cook, cook-chill, and cook-freeze systems in terms of operation and costs (Greathouse et al. 1989).
5. Provide better control of food production and ability to utilize technologies that provide desirable results (e.g. irradiation or pulsed electric field) since these may have limitations under a lower production scale.
6. Ability to reduce food waste since by-products/wastes can be used. Unlike conventional cooking (cook-serve system), cook-chill and related systems have the ability to cover any un-forecasted demand or losses.

In addition to the advantages mentioned above, Baldwin (2012) described several other advantages for sous-vide technology as follows:

1. Ability to control temperature precisely. This allows product consistency.
2. Temperature control can be translated into a better control over the product sensory properties (e.g. texture, colour) compared to traditional cooking methods.
3. Possible improvements to the tenderness of tough cuts of meat.

Fig. 7.2 Cook-chill central facility

Despite the numerous advantages that cook-chill, cook-freeze and sous-vide systems have the following disadvantages:

1. Requires specialized expensive equipment (Fig. 7.2).
2. Needs strict cold storage and cold chain requirements.
3. Requires thawing steps for freeze-chill foods.
4. Needs fast cooling without surface freezing.
5. In the cases of large packs, cooking continues inside the pack since cooling is not instantaneous. The use of heat exchangers may be useful to overcome this problem for pumpable materials, but it is not suitable for solid foods (i.e. meat, fish and large chunks of vegetables).
6. It may not be suitable for all types of foods and cuisines. For examples, grills and caramelized products cannot be generated using these technologies.

7.6 Processing of Cook-Chill/Sous-Vide and Cook-Freeze Products

A general layout of the cook-chill system is shown in Fig. 7.3. This demonstrates a series of steps or stages and each individual step is regarded equally important in order to maintain both safety and to produce good quality products. Cook-chill technique is simple, and shows flexibility in food service. The methodology involves the full cooking of food, followed by fast chilling and storage at cool *temperatures.* This can extend shelf life up to 5 days. Within the recommended storage period, the prepared foods can be served quickly after a re-heating step when stored within the recommended storage time. The production system itself is simple to operate and provides a consistent quality. A safe product can be obtained if recommended temperature/time controls are followed. Normally, the recommended minimum time required is 2 min at core (centre) temperature of 70 °C. The temperature of the product should be rapidly reduced from 60 to 7 °C to prevent any growth of certain micro-organisms. Further reduction to 3 °C is essential to reduce the growth of spoilage bacteria and pathogens. The main difference between cook-chill and cook-freeze is their final core temperature and the required cooling rates.

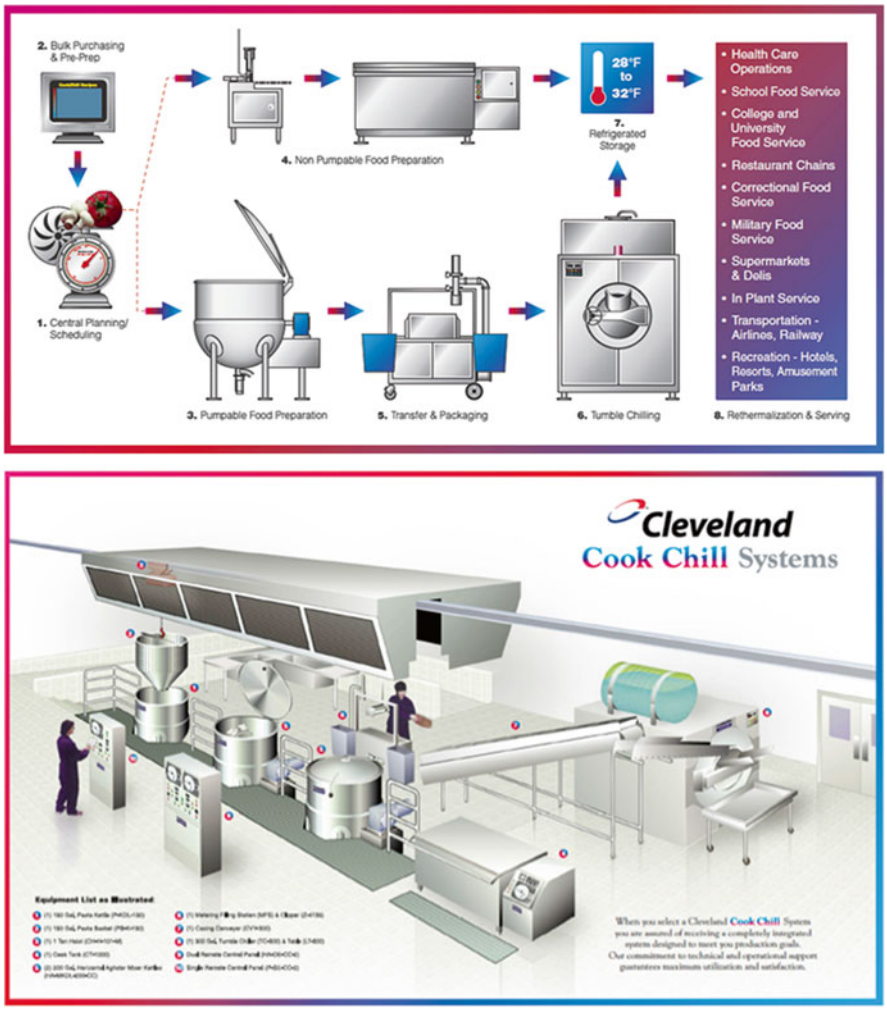

Fig. 7.3 Production line for cook-chill foods

Figure 7.4 shows a processing scheme of cook-chill/freeze products. The technology is a process that consists of blast freezing and frozen storage followed by thawing and then display at chill conditions (O'Leary et al. 2000; Zhang and Sun 2006).

7.6.1 Processing Conditions

Processing conditions require appropriate temperature and time and vacuum packaging (del Pulgar et al. 2013). Since the safety, nutritional value and sensory quality are the main concerns for cook-chill meals, it is essential to understand how

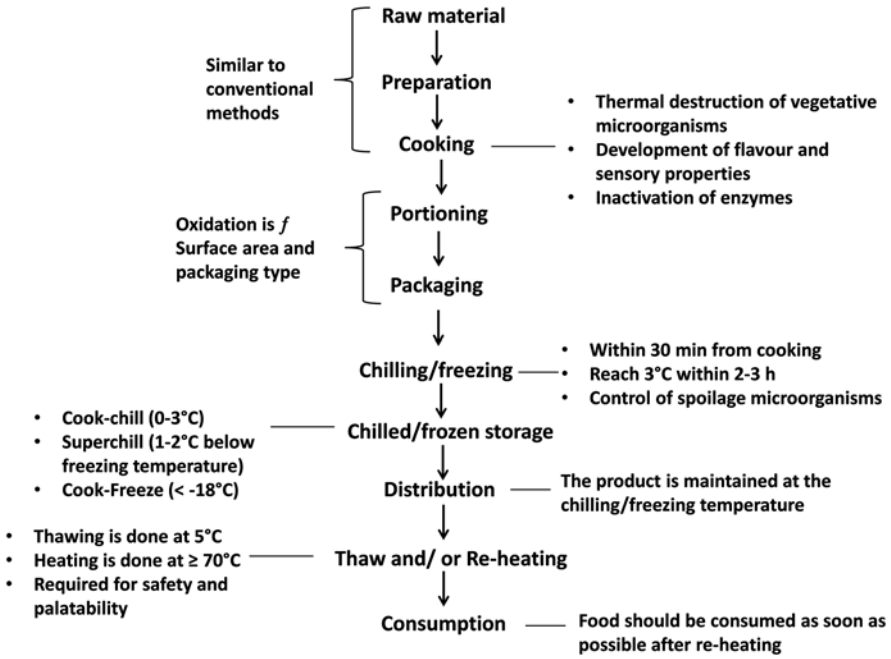

Fig. 7.4 Flow chart for different operations of cook/chill and cook-freeze foods

the cooking method (temperature and time) and processing technique (e.g. atmosphere, vacuum, and high pressure) affect quality. The preparation steps (i.e. including heating and cooling) are crucial factors for retaining nutritional value and sensory quality. High cooking temperatures or longer cooking times at moderate temperatures can deteriorate the appearance and texture of vegetables, e.g. degradation of chlorophyll in green beans during cooking (Stolle-Smits et al. 1997; Van Boekel 1999). Abuse of temperature during cooking, cooling or storage can promote further degradation of the sensory attributes (Krebbers et al. 2002; Martins et al. 2004). Therefore, temperature control is very important for achieving better sensory properties.

7.6.2 Production of Cook-Chill Products

7.6.2.1 Raw Materials and Ingredients

Various control measures must be implemented in order to reduce or eliminate contaminations of cook-chill foods at the initial stages of processing. Appropriate selection of raw materials and ingredients is the first step to achieve a high quality product. Control measures to produce consistent quality and safe products include washing, heating, disinfecting, sorting, grading, transportation and cold storage.

Applying quality control plans and good manufacturing practice to eliminate hazards and possible contamination can be integrated easily in cook-chill/cook-freeze production systems.

7.6.2.2 Heating Techniques

The most common systems used for cooking/heating are water bath or steam. However, conventional heating systems can produce an inconsistent heating profile, especially if large volumes of food are processed. Sheard and Rodger (1995) examined ten heating systems and reported that none of the convective steam ovens heated sous-vide pouches uniformly under fully loaded operational conditions. It took 16–85.5 min to increase the temperature of sous-vide pouches from 25 to 75 °C. The variations depend on the location of the product within the oven as well as the types of oven. The circulating water baths provided uniform heating with a variation of 0.05 °C. It is important to submerge the pouches (in a rack) during cooking to avoid undercooking or potential microbial growth during post-processing (Rybka-Rodgers 1999).

7.6.2.3 Rapid Chilling or Freezing Equipment

The refrigeration systems used for REFPFED are: blast chillers, blast freezers or combination of both. These are capable of rapid reduction of temperature of hot foods (+70 °C) to low safe storage temperatures (+3 °C or −18 °C). The basic principle of food safety in cook-chill food products is the start of cooling as soon as cooking is finished and the final core temperature of the product should be below 4 °C. This can be achieved using specially designed rapid chillers, such as air-blast chillers and vacuum coolers. These are capable of decreasing the temperature of the hot food to 0 °C or +3 °C within 90 min. This ensures the product safety as well as preserving the sensory attributes. As the final cooling temperature and the rate of cooling are crucial control points in this process, chillers are normally equipped with temperature probes at various locations to monitor the process.

There are two main methods of cooling used for cook-chill and sous-vide products: blast chilling and water bath chilling. In blast chilling, cold air circulates over food containers (usually shallow pans), while in the water bath method, cooked food containers are submersed in cold water. Rapid cooling or freezing (also known as hard blast chilling) is used for dense, large products with high fat content (e.g. meat based sauces, meat joints, mashed potato and lasagna). The air temperature of the cabinet, normally below the freezing temperature of the product, must ensure that the core of the product reaches the required +3 °C within the 90 min. A slower chilling rate is obtained by “soft blast chilling”. This technique uses air temperature above 0 °C in order to avoid any damage to delicate and light products, such as fish, rice, vegetables, cream, desserts, cakes and fried foods. Therefore, the soft blast chilling cycle smoothly lowers the product core temperature to +3 °C over 90 min without compromising the quality of delicate products.

For cook-freeze processing, the freezing must commence within 30 min of cooking and must achieve a core temperature of at least −5 °C within 90 min. The final temperature should be −20 °C or less. The cooling rates (from around 60 °C to +3 °C within 90 min) require very powerful refrigeration equipment that blows high velocity chilled air into the refrigerator to achieve cooling at high speed. The heat transfer increases with increasing air velocity (decreasing the boundary layer on the surface of the product) and temperature difference between the air and the product. In the case of direct contact with food products, stainless steel needs to be used for maintaining hygiene and easy cleaning. Hot food in bun pans or any other containers should be well spaced during blast chilling. The use of shallow containers is preferred since they can cool fast by minimizing the heat transfer resistance. The hot food should be uncovered so that an accelerated cooling rate can be achieved. This method is recommended for food that will be consumed within a few days (i.e. up to 5 days; Garrett 2012).

Another method used for rapid chilling is tumble chilling. After cooking and filling the product into casings, the product is loaded onto a rotary stainless steel chiller, which reduces the temperature of the cooked food below 4 °C within an hour (i.e. foods with low viscosity) or within 90 min for viscous foods. The bagged product is loaded into a drum which rotates in a chilled water tank (i.e. 400–4,000 l capacity). The water around the product is chilled by circulating a chilled refrigerant (e.g. propylene glycol) through a dimpled jacket in the outer casing of the unit. The primary cooling medium may be any refrigerant provided that heat exchange between both the refrigerant and the food is properly installed. A tumble chiller can hold from 25 to 450 kg of product in one cycle. This method is widely used and it results in consistent food quality with lower costs associated with energy and labour (Vomvoris 2005).

Another chilling system used is vacuum cooling. It has been traditionally used as a precooling technique for fresh leafy vegetables, such as spinach and lettuce (Elansari 2008). Several studies documented the use of vacuum cooling as an efficient technology to chill foods, such as cooked rice, ready meals and cooked meats (Drummond and Sun 2008). Vacuum cooling of cooked meat was investigated by Zhang and Sun (2006). Vacuum cooling can significantly increase the cooling rate of cooked meat. Vacuum cooling reduced the temperature of cooked meat from 70 to 74 to 4 °C in 1–2.5 h compared to air blast chilling, whereas slow air chilling, or water immersion chilling, took 9.4–11.7, 12.1–14.3 or 5–14.3 h, respectively. Zhang and Sun (2006) also reported superior processing efficiency (shorter cooling times, lower evaporative losses from product, and less water-spraying used) of vacuum cooling compared to the cold room, blast cooling and plate cooling of broccoli and carrot slices. The higher cooling rates obtained via vacuum cooling compared to other conventional cooling methods are due to differences in cooling mechanisms (Tragethon 2011). For conventional cooling methods, heat is mainly removed by an internal conductive heat transfer from the core of the product to the surface. The surface heat is then removed by convective heat transfer in cooled air or water. The internal heat transfer by conduction is slow due to the low thermal conductivity of cooked meat, and therefore it becomes the rate-limiting step. This explains why the

cooling rate of conventional systems is largely dependent on sample size (i.e. faster cooling time is obtained with small size samples; McDonald et al. 2000).

On the other hand, vacuum cooling takes place by evaporating water from the surface or pores inside the product at low atmospheric pressure (Kader 2002). Water evaporation takes place on the surface of the macro-pores of the materials followed by diffusion of water vapour through the pore spaces to the surface and subsequently water is lost to the surrounding atmosphere (Wang and Sun 2002). Therefore, the porous structure of the samples (e.g. pore size, pore shape, total pore spaces, pore distribution) plays a critical role in determining the water evaporation rate and subsequent vacuum cooling rate. Products that easily release water may cool to the desired chilling temperature in 20–30 min. Vegetables with high surface:mass ratio release water rapidly (e.g. leafy green vegetables, celery, sweet corn, green beans, carrots, and bell peppers) and these are best suited for this method. Boxes of film-wrapped cook-chill products can cool quickly provided the film allows easy movement of water vapor.

The operating temperatures in cook-chill and freeze-chill steps must therefore be sufficiently low to inhibit growth of the relevant microorganisms (Baerdemaeker and Nicolaï 1995). As mentioned earlier, the processing conditions applied (chilling rate and cold storage temperature) vary among different EC countries (James 1990). In France, the recommended temperature needs to be 10 °C, decreasing from 70 °C within 2 h, followed by storage within 0–3 °C. In other countries such as Denmark, Germany, Sweden and UK, the chilling times are 3 h (i.e. from 65 to 10 °C), 2 h (i.e. from 80 to 15 °C), 4 h (i.e. from 80 to 8 °C) and 1.5 h (i.e. from 70 to 3 °C), respectively (Hill 1994). It should be noted that these recommended times depend on the package size. For example, the guidelines of the Department of Health in the United Kingdom for cook-chill products are that 80-mm trays should be chilled below 10 °C in 2.5 h and the smaller 40- and 10-mm trays should be chilled below 3 °C in 1.5 h. These recommendations were verified using Bolognese sauce in trays with various sizes (Evans et al. 1996).

Inappropriate vacuum during processing leads to the formation of insulating air layers between product and package. This represents an additional resistance to heat transfer causing a delay in the cooling cycle and needs to be accounted in refrigeration load calculations. Other factors that need to be considered in the design of chilling processes are; (1) size, shape, weight of food and container; (2) material of the container; (3) density of food and its moisture content; (4) heat capacity of the food and the container; (5) thermal conductivity of the food; (6) design of the chiller, which affects chilling speed; (7) temperature of the food entering the chiller; and (8) lid or cover of the container (Hill 1994).

7.6.2.4 Packaging

The application of cook-chill packaged products in the food service industry can provide a buffer zone and flexibility in meal preparation. Packaging of sous-vide products provides an example of how packaging can significantly improve the

storage stability of products (Jang et al. 2006; Leistner and Gould 2002). Many products prepared by conventional and labour-intensive methods are now processed by cook-chill (especially sous-vide since 1980s). This is due to the perceived superior sensory qualities as well as the microbiological stability (Creed 1998; Werlein 1998). The application of sous-vide for traditional products are gaining lots of interest (Schafheitle and Light 1989; Simpson et al. 1994; Kim et al. 2001).

The sealed laminated-plastic pouch or containers under vacuum are used for sous-vide foods. These containers contain low oxygen partial pressure and prevent the growth of aerobic spoilage micro-organisms and lipid oxidation causing rancidity. Lipid oxidation generates off-flavours during refrigerated storage (Church and Parsons 2000). Vacuum pouches should provide good mechanical resistance, thermal tolerance (−40 to +120 °C) and provide excellent heat transfer capabilities. Vacuum packing also helps to maintain the product quality and to extend the product's shelf life by three- to fivefold.

For sous-vide, packs are typically brick-shaped with a thickness of 3–5 cm, whereas ready-meals/cook-chill bags are used with a wide range of shapes. The pressure inside the bag is preferably below 1.5 kPa for meat and vegetables (Rozier et al. 1990). In the case of liquid foods (e.g. sauces and soups) the inside pressure limit is 10 kPa (Baerdemaeker and Nicolaï 1995) since it is very difficult to achieve low pressure.

In the case of sous-vide, it is common to have inflated packages during re-heating if there is an insufficient vacuum (Baerdemaeker and Nicolaï 1995). Therefore, this effect needs to be considered for transfer calculations. Meals accompanied by sauces or other liquids represent a significant challenge for cook-chill/sous-vide processing due to their probability of rupturing during processing, handling and storage (Díaz et al. 2010). A recent trend to alleviate this problem is the use of plastic trays sealed under low oxygen conditions and the use of steam permeable plastic films. The plastic trays are commonly accompanied by gas mixture flushing. This can prevent failure of the packages, avoid mechanical damage, and eliminate headspace oxygen. A main disadvantage of this type of packaging is the formation of condensed moisture in the cooked product. However, these plastic trays are more robust, easier to fill (i.e. especially in the case of liquids), more attractive to consumers and the trays can be re-heated before consumption (Díaz et al. 2010). Thus it makes a very attractive option for the industry.

It was found that MAP conditions of 60 % CO_2/40 % N_2 extended the shelf life of prepared meals stored at 10 °C by 233 % (to 18.4 days) compared to the stretch-wrap air packaging (7.9 days; Lee et al. 2008). The shelf-life was determined based on the time required to grow anaerobic bacteria at 10^5 CFU/g. Moreover, the relative extension of the shelf life with MAP was greater under lower temperature storage. MAP was very effective in preserving the sensory properties and microbiological quality of a cook-chilled Korean traditional rice cake (backseolgi) stored at 3 °C (Lee et al. 2011). After 50 days of storage, MAP samples showed 1.0 log CFU/g, while low density polyethylene showed more than 5.0 logs CFU/g after 4 days.

Levkane et al. (2010) investigated the effect of the packaging technology on the microbial growth of sous-vide salad containing meat in mayonnaise. The product was either packed in polystyrene (PS) containers (of size 100 mm × 80 mm × 25 mm,

and polystyrene thickness 30 ± 3 μm) covered with non-hermetical lids, or sous-vide processed in polyamide/polyethylene (PA/PE) film pouches with barrier properties (of size 200 mm × 300 mm, and PA/PE film thickness of 20/45 μm). The products were chilled at either 4 or 10 °C for up to 52 days. Control samples were microbiologically spoiled after 10 days of cold storage at 4 °C. Sous-vide processing significantly reduced microbial growth at 4 or 10 °C and the product shelf life was extended to 52 days even at a chilling temperature of 10 °C. The benefits of packaging in the case of cook-chill under vacuum can be summarized as follows:

1. It can maintain delicate flavours (i.e. all the natural goodness and taste of food can be preserved for 4–6 days in the fridge or frozen storage for much longer periods, up to 2 years) (Newton and Gillespie 2010). There are negligible studies available in the literature on the effect of vacuum on the volatile profile of sous-vide cooked meat at low to moderate temperatures.
2. It can inhibit oxidation. Vacuum packing helps to preserve cook-chill food by removing oxygen-containing air inside the bag and thereby limiting deteriorative oxidative processes.
3. Vacuum packaging of food eliminates freezer burn by protecting the food from evaporation during frozen storage. Water loss from the surface can cause leathery appearance, discoloration, development of off-flavor and unacceptable texture. In a similar way, air circulation inside freezing rooms or cold stores causes moisture loss by evaporation from the product surfaces. Minimizing water loss can keep food moist and juicy.

7.6.2.5 Process Validation and Safety

Temperature control during heating, cooling and storage of cook-chill foods is very important. It has been reported that oven and cold store temperature measurements at selected central locations were not satisfactory (Baerdemaeker and Nicolaï 1995; Schellekens and Martens 1992). While non-homogenous spatial temperature distribution in the various heating or cooling systems can be expected, it is important to consider this point to calculate lethality and cooling rates. The overall effectiveness of the control should be validated according to the prevalence of microbial hazards, desired food safety levels, and perceived risk (Zwietering et al. 2010; CAC 2008).

The validation of cook-chill processes needs to consider the following steps: cooking, cooling, cold storage, transport to the catering facilities and reheating before serving (Poumeyrol et al. 2012). The most significant factor likely to lead to *Clostridium perfringens* outbreaks in cook-chill food is the cooling step (Golden et al. 2009; De Jong et al. 2005; Poumeyrol et al. 2012). The cooling step is often poorly controlled and not highly efficient in the catering sector (Olds et al. 2006). This is due to inappropriate equipment design and inadequate cooling capacity. This slow-cooling results in the germination of spores and growth of vegetative cells. To counter this hazard, guidelines and codes for cook-chill production have been established in different countries. These guidelines can avoid temperature abuse during the cooling step. The French public health authorities enforce a defined

temperature-time combination, from 63 to 10 °C within 2 h (French Ministry for Food, Agriculture and Fisheries 2003), while the USDA recommendation (2001) consists of two values, namely a cooling from 54 to 26 °C in less than 90 min and from 26 to 4 °C in less than 5 h. For the Australian and New Zealand Food Standards Code (NSW 2011), all cook-chill foods must be cooled after cooking in accordance with Food Standards Code requirements (the '2-h/4-h cooling rule'): (a) within 2 h—from 60 to 21 °C, and (b) within a further 4 h, from 21 to 5 °C, unless the processor can demonstrate that the cooling process used by them will not adversely affect the food safety.

Several cases of temperature abuse have been reported in the literature (Jaloustre 2011; Poumeyrol et al. 2012). For example, there are cases when the product was removed from the blast-chillers at a temperature above 10 °C, but this temperature was not representative of the bulk average temperature of the whole batch (i.e. some packs were substantially higher than 10 °C). This can potentially cause problems with shelf life and product safety. In addition, effective systems of temperature measurement are needed to be in place to enable validation of cooling processes.

7.6.2.6 Freezing as an Alternative

If temperature abuse occurs with sous-vide and cook-chill foods, these may become a source of health risk. This is due to the potential anaerobic growth of *C. botulinum* spores in the food (Gould 1999; Gaze and Brown 1990; Bolton et al. 2000; Tansey et al. 2010). The risk of temperature abuse is greater during different stages of the food handling process, such as during transport and storage at the final destination (i.e. home, hotel or any other catering facility). Therefore, frozen sous-vide or a cooked food is regarded as a safer alternative to sous-vide-chilling and cook-chill processing. As mentioned earlier, cook-freeze process is the same as the cook-chill process, except the cook-freeze product is frozen to –20 °C in the central processing facility. In the catering sector, cook-freeze food can be stored for up to 8 weeks before it is reheated for consumption. The potential growth of *C. botulinum spores* are eliminated by freezing (Tansey et al. 2010). Freeze-chill technology involves initial freezing and frozen storage (–30 °C or colder), followed by thawing and chilled retail display usually at 4 °C (O'Leary et al. 2000; Redmond et al. 2004). Freeze-chill technology allows 'chilled' foods to reach more distant markets, facilitates bulk production, and reduces the level of product recalls.

Cook-freeze and freeze-chill processing may not be suitable for all food products and can adversely affect the quality attributes of some food items. For example, it was reported that freeze-chilling leads to a reduction in the vitamin C content of mashed potato (Redmond et al. 2004). In addition, freezing affects texture due to structural damage from ice crystal formation. Depending on the freezing rate, several physical changes are associated with the formation of large sharp edged ice crystals, combined with volume expansion, and disruption of the osmotic equilibrium between the cells and their surroundings. These may cause irreversible damage to the texture of vegetables, fruits and meats. The ice crystals formed during slow

freezing of vegetables leads to loss in cell turgor pressure, weakening the cell wall, increased permeability across cell walls, and consequently a softer texture and higher drip loss on thawing (Fuchigami et al. 1995; Préstamo et al. 1998). Fast freezing rates result in the formation of a larger number of ice nuclei and consequently smaller ice crystals and firmer texture (Fuchigami et al. 1995; Rahman et al. 1971). Frozen storage temperature also influences the texture of vegetables. The lower frozen storage temperatures result in slower growth in the size of ice crystals and may prevent re-crystallization, and consequently yield optimum texture preservation (Kennedy 2003).

7.6.2.7 Thawing and/or Reheating and Serving

Cook-freeze and freeze-chill technologies require thawing of the frozen food prior to retail display and consumption. It is essential that the system design and selection allow thawing and all ice crystals are entirely thawed before the food is re-cooked. Any remaining unthawed parts upon subsequent re-heating may not achieve adequate safe and well-distributed temperature environments, which can present an increased risk of food poisoning (Barrie 1996; Brown et al. 2006).

Generally, thawing occurs more slowly than freezing and foods are subjected to more damage during thawing (Li and Sun 2002). The difference between freezing rate verses thawing rate are due to differences in thermal conductivity and diffusivity of water and ice (Park et al. 2006). In addition, the temperature of foods increases rapidly just before freezing, while there is a long lag time for phase transition at the freezing and melting plateau leading to tissue damage due to re-crystallisation, microbial activity and physicochemical changes (Fennema et al. 1973). Therefore, optimum thawing procedures should be implemented for cook-freeze foods (Fennema et al. 1973; Kalichevsky et al. 1995).

During thawing, temperatures must not rise above 10 °C according to the UK guidelines (Anon 1989), but a stricter thawing practice is recommended in Australia (i.e. no more than 5 °C; NSW Food Authority 2011). Following thawing, it is recommended that the temperature of the food must be reduced to below 3 °C homogeneously throughout the food within 12 h. In practice, this means that any thawing process greater than 3 °C must be followed by a temperature reduction stage, termed re-cooling (Brown et al. 2006).

Thawing of cook-freeze foods should be done under conditions that minimize microbial growth. Thawing methods used in the food industry vary in terms of thawing media as well as the nature of the heating applied. The thawing methods include the use of hot air, immersion in warm liquids, steam at ambient pressure or under reduced pressure. These reduce surface temperature gains, while higher surface temperatures are observed during microwave or direct contact heating plates (Koke et al. 2002). New methods have been developed more recently, including high-pressure and acoustic thawing (Li and Sun 2002). Thawing at ambient temperature can lead to the uncontrolled and unrecognized growth of pathogens and

should only be applied when risks have been properly assessed. A controlled thawing cabinet with hot air is the most common applied method for this purpose. However, microwaves or steam are not practically suitable for cook-freeze products, since they cause undesirable surface conditions. Thawing using a microwave oven may leave cold spots at the core of the food unless the microwave is specifically designed to ensure even thawing.

Thawing is a critical process and must be considered within a HACCP plan. Hazards associated with thawing include cross-contamination from the drip and growth of micro-organisms on the outside of the package before inside thawing. Thawed meat and poultry products should be checked frequently to make sure of a complete thawing process before further processing. As a general rule, rapidly thawed foods in fast thawing cabinets should be consumed within 24 h. Thawed foods should not be re-frozen due to quality and safety issues.

Similar to the freezing rate prediction models of foods, several thermodynamic models of the thawing process have been reported in the literature (Cleland et al. 1986; Salvadori and Mascheroni 1991; Ramos et al. 1994; Ilicali et al. 1999). The key feature of these models is the analytical equations for predicting a thawing time, which relates to the melting of all ice in the product. However, temperature time history of the product should also modeled for complete thawing. Therefore, data on thawing times for foods in cook-freeze packs are essential for correct design and operation of these systems. Computer modelling was used to identify the fastest and slowest thawing packs from a typical hospital catering range (Brown et al. 2006). It is important that practical systems are able to achieve acceptable uniformity of air temperature and velocity over each and every pack, otherwise thawing times can vary greatly. This requires careful design of air flow and pack spacing, otherwise it would be necessary to allow considerable tolerances in thawing times.

7.6.2.8 Reheating

Cook-chill products are fully cooked and stored chilled until their consumption. At the time of use/consumption the food is often reheated to achieve: (1) improved product aroma and flavour resulting from the generated volatiles during the heating step, and improved palatability due to changes in the perceived texture, and (2) improved food safety by killing any microorganisms that may be present in the stored product.

Reheating (also called re-thermalization) should be initiated before food consumption (i.e. within 30 min from the removal of the food from chilled storage). Reheating can be carried out using microwaves, forced air and steam convection ovens. Traditional hot-air ovens can potentially cause drying of exposed areas of the food. Commercial microwave ovens are very efficient in terms of time and energy use, but are recommended for the reheating of individual portions or small numbers of meals. Other options of reheating methods include: infrared ovens, hot water baths, convection steamers, combination steamer/ovens, and hot plates (Yang 1990).

Reheating foods by one of the above mentioned methods provides an efficient means to prepare the number of meals required at a given time, thus minimizing food wastage.

The use of retherm carts to reheat meals is a more recent development in hospital food services. The retherm cart electric heating discs are used to warm meals in a refrigerated room, while other chilled products such as fruits and drinks, and remain chilled until service. This system can heat between 12 and 26 meals on metal trays. Reheating of cook-chill food products should be strictly carried out by trained personnel under strict conditions. This step can significantly impact the nutritional quality of food, for example significant losses of thiamin and ascorbic acid are reported to occur during long heating periods (Edwards and Hartwell 2006; McErlain et al. 2001).

7.6.2.9 Facility Design and Equipment

The ultimate objective of cook-chill process design is to automate and control the stages of the prepared food manufacturing so that it can occur as a steady and smooth process, rather more typical peak-and-valley method of most kitchens. Food quality can be fine-tuned in cook-chill processing through strict adherence to standardized recipes and procedures to ensure a sustainable and consistent product. It is important to design processing facility solely for a particular food preparation process (i.e. cook-chill). Conventional walk-in refrigeration units cannot reduce food temperatures quickly, and therefore should not be an alternative for the air blast freezer. The equipment needs automatic transfer, portion control, and packaging of finished cook-chill foods. The layout and design of the facility, equipment and maintenance need to be designed properly.

The layout and design of the facility should allow an efficient flow of work that facilitates movement of both products and personnel through the facility. The food should ideally move the shortest distance possible with reduced crossing paths as much as possible. One example of a food workflow is shown in the flow chart in Fig. 7.5. The layout should also maximize the productivity of employees and take into consideration the possibility of future expansion. All utilities such as water supply, drainage, electricity and lighting should be provided at the right locations with good safety and sanitary considerations. The total amount of space required for the facility needs to adequately accommodate all equipment and processes. Appropriate space is needed for clearways to satisfy the movement of cart, forklift and the pallet jacks. Adequate space is required for accessing equipment for maintenance and cleaning. The main functional facilities should be properly laid out, include areas for receiving and storage of raw product, hot food preparation, cold food preparation, bakery, packaging, assembly, storage of prepared foods, shipping/distribution, and equipment cleaning.

The type of equipment, size and their sequence influences the layout and design of the facility of the production. Moreover, the required equipment layout depends

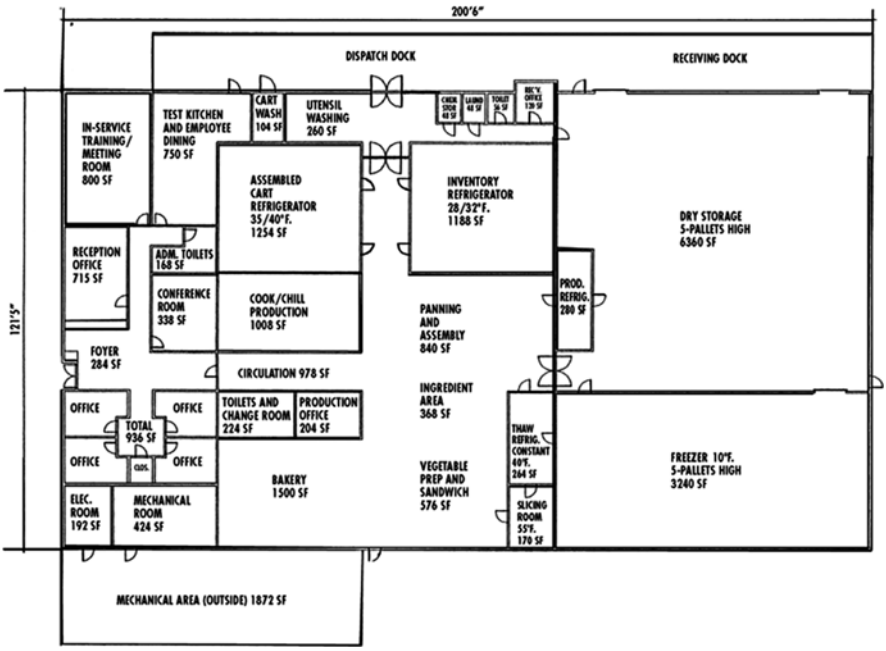

Fig. 7.5 Layout and design of a food processing facility

on the desired items and the functional areas used. Equipment sizing and selection should be based on detailed technical specifications and it should provide fine control, robust, hygiene, durability, less maintenance and power saving options and capabilities. The specifications do not only describe equipment, but also include information about electrical requirements, plumbing requirements, steam requirements, and mechanical requirements. The specifications should also include information concerning freight, delivery and installation requirements, handing over conditions, warranty and extended warranties, instructions for installation and removal of old equipment and training required (NFSMI 2002).

A progressive maintenance plan (preventive and predictive) for equipment must be developed to ensure that the facility can meet the sustainable production objectives and minimize any delay caused by an emergency breakdown. The impact of an equipment breakdown in a facility would have a significant cost on the production and interrupt the scheduled operations. Thus, detailed and supported plans must be in place for both preventive and predictive maintenance along with an inventory of spare parts needed and trained persons. A health and safety emergency plan should be developed to guide workers in certain circumstances, such as a power outage. Other items should be considered include design of the dryer, chilling and freezing warehouses and careful planning for it. In addition, a waste management system should be in place based on the rules of the local authority.

7.6.2.10 Thermal Properties and Prediction Models

The thermophysical properties of foods depends on the heat and mass transfer mechanisms, phase changes involved, and chemical reactions during chilling, freezing or heating. These characteristics include temperature and velocity, fluid properties such as viscosity, density, conductivity, and heat capacity, product surface properties such as geometry and dimension, and internal structure or arrangements. The dielectric properties of foods are very important for microwave heating. Due to the interaction of these parameters, the boundary layers can be very complex, therefore predicting the cooling time by considering all the above factors can be a difficult task (Hu and Sun 1999, 2000).

Convection heat transfer is the major mode of heat transfer between the surface of a solid material and the surrounding fluid. The rate of convective heat transfer depends on the properties of the fluid and the fluid flow characteristics. Originally as suggested by Prandtl, the resistance to heat transfer may be considered to be localized in a boundary layer within the fluid present at the surface of the solid material. Although this concept is for ideal situations, it has been widely used in studying convective heat transfer. Commercial numerical techniques, such as computational fluid dynamics (CFD) using CFX software have been successfully adapted to the food industry to simulate the thermal process. This can provide a better understanding of the mechanism and aid in the improvement of design and operation (Anon 1997). Recently, a number of models have been developed for predicting the food chilling process and the influence of its thermal properties (Chuntranuluck et al. 1998; Kuitche and Daudin 1996; Davey and Pham 1997; Maroulis et al. 1995; Hu and Sun 1999, 2000; Xia and Sun 2002; Kaushal and Sharma 2012).

Computational fluid dynamics can be used for other equipment designs, for detailed product development and for scale-up of the process. The microbiological stability and safety of sous-vide products is mainly determined by the different thermal treatments including heating, cooling and reheating. The theoretical aspects of the different modes of heat transfer relevant to 'sous-vide' cooking can be optimized using computational techniques such as the finite element method and CFD. These techniques can provide a powerful means to investigate the effect of modifications in the processing conditions on the internal temperature of the food (Baerdemaeker and Nicolaï 1995).

A CFD model to study heat and mass transfer of a cylindrical shaped cooked meat within an air-blast chiller was carried out to predict its cooling rate and weight loss during chilling (Hu and Sun 2000). The investigation was based on a mathematical analytical model of unsteady heat and mass transfer with the assumption of a homogeneous heat transfer coefficient (i.e. which takes into account the effects of forced convection, radiation and moisture evaporation on the surface of the cooked meat joint). This method allows the simultaneous CFD prediction of both temperature distribution and weight loss in the meat throughout the chilling process. Cooling time and weight loss from 75 to 3.5 °C were approximately 530 min and 4.25 %,

respectively, by both experiment and prediction model. The simulation using CFD can be easily adapted to other elementary shapes, operating conditions of the cook-chill production chain.

7.6.2.11 Effect on Texture and Nutrition

Cooking can have a dramatic effect on the texture of food depending on the cooking temperature, food material structure/composition/condition and method of cooking. The cook-chill process produced more soft cooked dry peas than sous-vide cooking due to the higher temperature of cook-chill processing. This improvement is due to moisture uptake (Xie 2000). MAP cook-chilled Korean traditional rice cakes scored significantly higher than LDPE packaging after 50 days of storage at 3 °C (Lee et al. 2011). Sous-vide processing reduced stem broccoli texture (softening %) by 54–58 % (i.e. a pleasant and moderate softening level). It was one of the treatments (as well as grilling and steaming compared to vacuum boiling, conventional boiling, pressure cooking, and microwaving) that induced the lowest stem colour changes (Martínez-Hernández et al. 2013).

While sous-vide processing decreased the total folate contents in potato and broccoli by 20.9 and 16.5 %, respectively, total folate content was increased by 4.9 % in sous-vide processed, cooled and reheated potato (Stea et al. 2006). However, other ingredients are used during the assembly of the meals, thus new nutrient profiles may arise. Shakila et al. (2012) reported the reduction of saturated fatty acids and an increase in the polyunsaturated fatty acids in the case of sous-vide processing of fish curry. While the observed changes are likely to be related to the inclusion of other ingredients, it demonstrated the ability of the technology to manipulate the nutritional composition favourably. The total antioxidant capacity of broccoli was increased by sous-vide, microwaving and frying compared to steaming, pressure cooking, and conventional boiling as well as in the raw state (Martínez-Hernández et al. 2013).

7.7 Conclusion

Refrigerated cook-chill foods deliver convenience and safety with retention of nutritional content. The quickly prepared meals are needed for families and individuals depending on their life style. The good safety track record of cook-freeze and sous-vide food products has created a trust. These are considered very acceptable and are seen as a better alternative for branded fast food. Appropriate processing conditions for microbiological safe cook-chill products are relatively established for many products. Challenges that require future research are: (1) optimizing the sensory quality of the food, and (2) developing a wide range of menus so that these can match cook-serve options. These products are appealing, however strict handling conditions need to be implemented.

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Chapter 8
Part-Baked Products

Mehmet Murat Karaoglu

8.1 Introduction

Baked or bakery products are very wide in varieties, including breads, rolls, cookies, cakes, pies, muffins, biscuits, doughnuts and pastries. It is an important part of a balanced diet and a wide variety of such products can be found in the supermarket shelves (Stanley et al. 2007). Bakery products, especially bread, cake, rolls, muffin, pastry, and other similar products have a limited shelf life. Physicochemical changes such as staling and firming, and microbiological spoilage such as yeast, mould, and bacterial growth reduces the shelf life of these products. Staling in these products results decreased consumer acceptance and thereby great economic losses. Because bakery products are an important part of the diet of people in many countries, the economic losses arising from staling are extremely important. For this reason, considerable attention has been given on staling of bakery products. Several studies have been reported to extend the quality and shelf life by retarding staling (Karaoglu and Kotancılar 2006).

Consumers want to buy wide varieties of baked products that is fresh. For this reason, the partial baking process is currently a convenient alternative for many bakery products. Fresh bread and similar soft bakery products usually present an appealing brownish, crispy, and crunchy crust as well as a pleasant aroma and a soft elastic crumb texture. These are important sensory characteristics (Altamirano-Fortoul and Rosell 2010). Part-baking method involves two stages of baking and its process provides an opportunity to supply fresh baked product with a simple baking stage at retail locations.

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8.2 Baking Process and Structure Formation

The baking process is the most important step for the production of baked products. This stage transforms the raw dough or batter (i.e. flour, water and leavening agents) to bread, cake or other bakery products with unique sensory features. This process is achieved by the application of heat inside an oven. The most apparent changes occurring during baking are volume expansion, crust formation, inactivation of yeast and enzymatic, protein coagulation, gelatinization of starch, formation of a porous structure and thermal expansion by carbon dioxide (i.e. produced by leavening agents) and water vapor (Sablani et al. 1998; Chang 2006; Purlis 2010a, 2011).

During baking, sufficient time should be given for the overall changes in the attributes as discussed earlier. Rapid baking of dough results in a faster staling after baking process (Le Bail et al. 2009). Because of the above-mentioned changes, the dough is transformed into crumb and then crust is subsequently formed due to water evaporation, cross-linking reactions, and browning development (Purlis 2011). Cellular structure of soft baked products crumb is a vital quality indicator used in commercial baking (Fig. 8.1) (Scanlon and Zghal 2001). The baking conditions are very important in order to attain the desired quality. These conditions are generally adjusted according to the time-temperature combination (Cauvain and Young 2000). The transformation of dough into bread during baking involves important structural changes (Table 8.1). For example, during baking at 220 °C, dough expansion and coalescence of the bubbles occur during the first 200–250 s, while a semi rigid elastic solid or crumb take place up to 400 s. At longer time, significant structural changes do not occur in these dough as indicated by the values of the crumb features and fractal dimensions obtained (Perez-Nieto et al. 2010).

Leavened dough prepared by chemical or biological liveners. Many quality aspects of baked products are the result of a series of irreversible physical and chemical changes produced by simultaneous heat and mass transfer. The most significant change occurs in starch and proteins. The denaturation of proteins releases water while the gelatinization of starch absorbs water. These two phenomena occur during the same temperature interval of 60–85 °C, and these contribute to the crumb

Fig. 8.1 Digital image of bread crumb from a *white* sandwich bread

Table 8.1 Overall physical, chemical and biochemical changes in dough occurring by temperature during the baking process (http://www.classofoods.com/page2_3.htm)

Temperature increase (°C)	Changes in dough
30	Because of the rising temperature, gasses present in the dough expand
	Enzymatic production of sugars
	Solubility of CO_2 decreases
45–50	Yeast dies
50–60	Intensive enzymatic activity
	Starch starts to gelatinize
60–80	End of the gelatinization of starch
	Enzymatic activity ceases because of the denaturation of the enzymes
	Crumb starts to form
	Interaction between gluten and starch
100	Water starts to boil
	Formation of water vapor
	First signs of crust formation
110–120	Formation of pale yellow dextrins in the crust
130–140	Formation of brownish dextrins in the crust
140–150	Start of caramelization process
150–200	Formation of the "crustiness" of the bread and aromatic compounds
>200	Carbonization of the crust
	Formation of a porous black mass

structure (Thorvaldsson and Skjöldebrand 1998). The other changes are the formation of carbon dioxide by leavening agents, crust formation, development of browning by Maillard and caramelization reaction. Phase changes such as water evaporization, and bubble expansion and coalescence are also occurred (Fan et al. 1999; Singh and Bhattacharya 2005; Purlis 2010a). Another major event during baking is the loss of water from the product. The amounts loss during baking are directly related to baking time and temperature (i.e. quantity of energy input). Water significantly affects the quality of bakery products. However, certain level of water needs to be kept during baking followed by cooling (Cauvain and Young 2000).

Baking is a process of heat gain and moisture loss (Cauvain and Young 2000). Baking is considered as a simultaneous heat and mass transfer in a porous medium. The temperature increase in a gas-free dough occurs at much slower rate than in fermented dough. The conductive heat transfer is considered relatively minor importance in dough baking, and evaporation-condensation is the major mechanism of heat transport in baking. The theory of evaporation and condensation are as follows: (1) Water evaporates from the warmer region, absorbing latent heat of vaporization, (2) Water vapor migrates through the gas phase, (3) The vapor condenses at the colder side of the gas cell and releases its latent heat and, (4) Heat and water transport by conduction and diffusion, respectively.

Evaporation-condensation will continue until the temperature of the whole crumb has achieved 100 °C (Wagner et al. 2007; Purlis and Salvadori 2009). During baking, the internal temperature of the dough reaches up to 100 °C, and three important changes take place in the dough properties. These are dough expansion (volume increase to 4–5-fold of its initial volume), a predominantly elastic crumb, and interconnected cell formation (Singh and Bhattacharya 2005). The early stages of baking plays a significant role in determining the resultant loaf volume and bread quality (Fan et al. 1999). In the initial stages of baking, dough forms a bubbly structure with an almost uniform density. The material surrounding the bubbles is initially liquid. In the later stages of baking, material properties of the matrix changes, and relatively negligible changes occurs at the end of the baking process. As the temperature inside the dough increases, the pressure inside the bubbles rises due to the water evaporating and therefore the dough expands (Jefferson et al. 2007).

One of the objectives of baking is to obtain a particular colour on the surface of baked products. The surface colour, texture and aroma play a significant role in producing quality baked products. For this reason, surface colour may be considered a critical index of baking (Zanoni et al. 1995a). During baking, the water content of crust decreases and the temperature of the surface can exceed 100 °C and Maillard and caramelization reactions develop colour and desired flavours (Vanina et al. 2009). The surface colour is also called as surface browning (i.e. yellow-gold colour formation) (Fig. 8.2). Since browning can be easily monitored during the baking process by in-line sensors, it is can be used as a control parameter to observe the extend of process (Purlis and Salvadori 2007; Purlis 2010a, b). Figure 8.3 shows the formation of browning (i.e. crust colour) at an oven temperature of 250 °C.

Another factor that determines the baking time is starch gelatinization during baking. Many starch granules may remain intact and their irregular shape depends

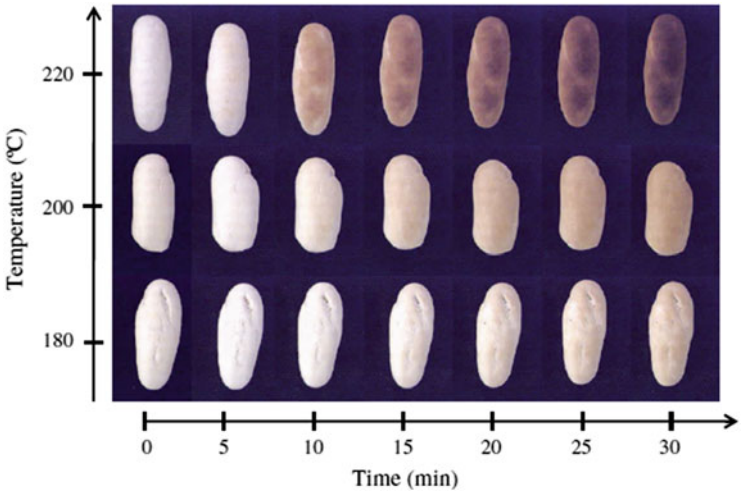

Fig. 8.2 Surface color of bread baked at different time and temperature (Purlis 2010b)

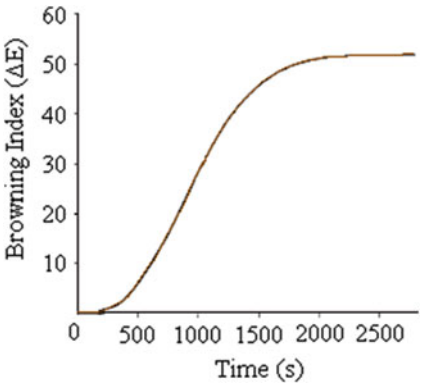

Fig. 8.3 Browning profile of bread baked at 250 °C (Zanoni et al. 1995a)

on the available water and temperature of baking (Aissa et al. 2010). A complete starch gelatinization in the crumb should be considered the first quality index of soft baked products, such as breads and cakes. If starch gelatinization does not occur during the baking, the quality (i.e. texture and appearance) of the product cannot be ensured. For this reason, the degree of gelatinization is also used as a baking index (Zanoni et al. 1995b).

8.3 Staling of Baked Products

Bakery products during storage are subjected to several changes and affect the quality of the products ranging from staling to total spoilage. The shelf life of these products is defined as the time when quality losses do not exceed a tolerated level and it can be decisively influenced by its storage conditions (Karaoğlu et al. 2008).

Bread and similar baked products have a limited shelf life. Physicochemical changes such as staling, textural changes, and microbiological spoilage (i.e. yeast, mould, bacterial growth) shortens the shelf life. Staling is defined as "almost any change, sort of microbiological spoilage, that occurs in bread or other products, during the post baking period, making it less acceptable to the consumer" (Smith et al. 2004). For this reason, considerable attention has been focused in controlling the staling of baked products (Bechtel 1953; Karaoğlu and Kotancılar 2006).

Staling involves the softening of the crust and the hardening of the crumb. The softening of the crust is a consequence of the migration of water from the crumb to the crust. However, the hardening of the crumb is more responsible for staling and it is a complex phenomenon where multiple mechanisms are involved (Ronda et al. 2011). The staling is a process of chemical and physical changes such as moisture redistribution, drying, starch retrogradation, increased firmness as well as loss of aroma and flavour (Karaoğlu et al. 2008). Cereal flour constituent of bakery products, contains carbohydrates, proteins and lipids or fats. Since starch is the

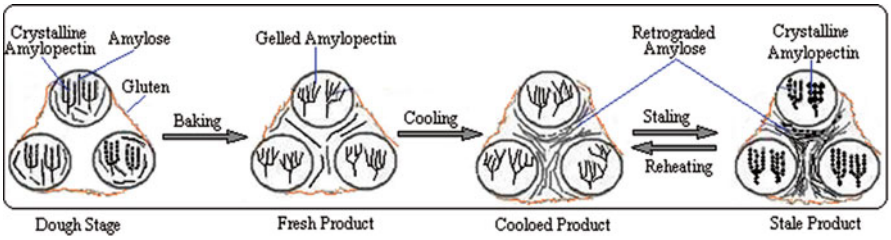

Fig. 8.4 Staling mechanism of soft bakery products

major constituent in these products, the physical changes accompanying the starch retrogradation is the main cause of staling (Barcenasa et al. 2003; Karaoğlu 2006a). Soft bakery products dries and hardens mainly due to starch retrogradation as well as because of cross-linking between continuous protein matrix and starch granule with hydrogen bonds (Novotni et al. 2011).

In general, staling process is largely part of two different sub-processes. These are the firming effect produced by moisture transfer from crumb to crust, and the intrinsic firming of the cell wall material (i.e. starch re-crystallization during storage) (Fig. 8.4) (Pateras 2007). In the later stages of staling, the mobility of water decreases due to increase of re-association and re-crystallisation of amylopectin (Curic et al. 2008). Starch granules in their native form have a semi-crystalline structure, which is composed of the polysaccharides (i.e. amylose and amylopectin) (Crowther 2012). When bakery products are baked in an oven, starch granules absorb water, swell in size, and then transform from a crystalline to amorphous form. This is referred to the "gelatinization" phenomenon. Immediately after the baking process, the swollen starch granules in baked products transform from amorphous to a more crystalline form and these lose their elasticity causing the crumb hard and brittle. This transformation is called starch retrogradation and is thought to be the major cause of crumb firming on ageing, commonly referred to staling (Hug-Iten et al. 1999).

Staling of bakery products has been extensively investigated because of its importance in determining product acceptability and shelf life. The staling process can be controlled by maintaining appropriate product formulation, processing conditions, packaging and storage. The crumb firming is related to starch-gluten interactions of bakery products. The process of aging can be retarded by adding anti-staling agents, such as fat, milk, whey, and enzymes. However, bakery products rapidly lose freshness (texture and flavour) (Karaoğlu and Kotancılar 2006; Cauvain 2004). Emulsifiers and similar agents have been used as anti-staling agents for years; but they actually have a limited effect and these require special labelling rules. However, new methods such as partial baking of the bakery products is an effective way of delaying the staling process of the baked goods (Table 8.2) (Karaoğlu 2006a). Re-baking process applied to part-baked product eliminates adverse changes in bakery products.

Table 8.2 Fresh baked bread alternatives (Lallemand Baking Update 2008)

	Applications	Advantages	Disadvantages	Bread types
Scratch baking	Artisanal and in-store bakeries	High quality and large variety of	Labor intensive (skilled), costly, time-consuming	Mainly crusty
Frozen bread	Thaw and sell	Facilitates production planning	Extra costs for freezing and frozen storage	Mainly noncrusty
Part-baked bread	Brown and serve	Freshly baked flavor, ambient storage	Only small loaves, time and temperature of 2nd bake critical	Mainly noncrusty
	Parbaked frozen	Fast and convenient (reheating) bake-off	High costs due to high volume of frozen storage	Mainly crusty
	Milton-Keynes	Fast and convenient (reheating) bake-off, ambient storage	Additional production equipment (vacuum cooler), 1st and 2nd bake critical	Mainly crusty
Frozen dough	Standard frozen dough	Cost-effective due to small volume of dough stored frozen	Inflexible (time for thawing and proofing)	Crusty and noncrusty
	Preproofed frozen dough	Fast, but requires programmable oven to bake frozen dough	Larger volume for storing frozen dough, lower volume for final products	Mainly crusty
	Substrate-limited frozen dough	Cost-effective due to small volume of dough stored frozen	Flexible, but requires special yeast	Only crusty

8.4 Reheat of Bakery Products

Retrogradation of amylose especially amylopectin is a major factor in staling of baked products. Retrograded amylopectin reverts to its amorphous state when approximately 50 °C temperature is applied. Nevertheless, the retrogradation of amylose is irreversible at such low temperatures and therefore very high temperature (i.e. 140–150 °C) is required for this transformation (Walt 1971; Karaoğlu 2006b). Unlike starch retrogradation, protein denaturation and moisture redistribution cannot be reversed by heating (Karaoğlu 2006b).

Once bread is baked, it contains open structure and it can be dried out very quickly (Lallemand Baking Update 2008). Many consumers refresh aged baked products with heat to eliminate the "staling" phenomenon. However, it is well known that a slight amount of overheating creates a pronounced toughening. The physico-chemical mechanisms of such refreshing is not exactly understood. When a staled bakery product is reheated up to a certain temperature, the increased firmness value of crumb is significantly reduced. However, after the product is re-freshened by heat, firmness increases more rapidly after its re-freshened (Karaoğlu 2006b).

Freezing and frozen storage of fully baked bakery products is the most effective methods for slowing down the staling (Fik and Surowka 2002). Bakery products, especially bread are usually kept frozen for use over long periods, and it can thawed and reheated just before consumption. Although it is widely accepted that reheating inverts the staling process, this is not enough to recover all the quality characteristics (i.e. smoothness) of the freshly baked bread. Bakery products are partially baked until the crumb is formed without starting the browning reactions, and it can be rapidly frozen. Re-baking can produce similar characteristics as fresh product (Barcenas and Rosell 2006a). Fik and Surowka (2002) reported that frozen bread with 71 % fraction of baking time showed high stability, and retained sensory features.

8.5 Part-Baking Process

Freshly baked products maintain flavourful yeasty aroma, sweet taste, soft and resilient texture. The freshness of bakery products can be lost quickly over time. This loss of freshness is due to a series of slow chemical and physical changes. This leads to progressive increase in firmness of crumb (i.e. staling). Food scientists and the baking industry are trying to find solutions to maintain the freshness and to extend the shelf life of bakery products (Sargent 2008). Different new methods are being developed to delay these undesirable changes. These methods include additives, such as emulsifiers, hydrocolloids, proteins and/or enzyme. In addition, optimum processing and storage conditions can play a role (Leuschner et al. 1997; Fik and Surowka 2002; Poinot et al. 2008).

Terms such as "part-baked," "part-baking," "partially baked," and "par-bake" are used to describe a method of bread manufacture, which involves two stages of baking (Fig. 8.5). Part-baking is a process of two stages. First, proofed dough pieces are partially baked under desired oven condition. At this stage, the minimum crust colour development, maximum moisture retention, starch gelatinization, and gluten coagulation occur in partially baked bread (Bent 1998; Karaoğlu 2006c).

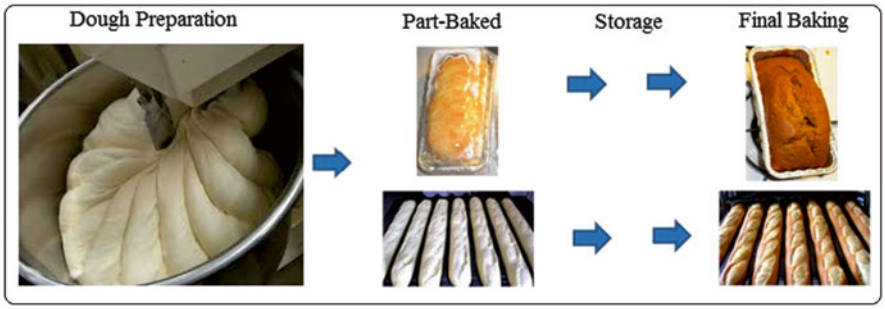

Fig. 8.5 Flow chart of part-baked products

During the prebaking or par-baking step, the products should be baked until crumb formation allows its storage for longer time. In the second step, partial-baked breads are rapidly cooled, wrapped, and stored until its final baking at the point of sale or consumption. The final baking process reverses certain product properties and generates its characteristics similar to the freshly baked product (Grau et al. 1999; Vulicevic et al. 2004; Barcenas and Rosell 2006c). Part-baking has a market potential because it provides fresh baked product with a simple baking stage at home or at the point of sale (Karaoğlu et al. 2008).

8.5.1 Initial Baking (Part-Baking)

Part-baking involves sufficient baking of dough to inactivate the yeast and enzymes, and to set the structure with a minimum crust coloration and moisture loss. Generally, lower baking temperature is required to avoid excess crust colouring. However, lower baking time efficiently extends the period of yeast activity at the beginning of the first baking. For this reason, a compensatory reduction in proof time is required. Steam may be applied during both of the baking stages. In the first baking stage, baking temperature is kept lower to produce scratch. The application of limited steam may be used to control the oven spring, or break (Cauvain and Young 2000, 2006). The amount of steam significantly affects colour, glossiness, and mechanical properties of the crust. The increase of applied steam caused a reduction in colour, failure force, and failure firmness, whereas increased glossiness (Altamirano-Fortoul et al. 2012). The objective of part baking is to bake the crumb without colouring the crust. Baking conditions such as steaming, temperature, and time are the most important factors affecting coloration of the crust. Optimum balance must be used to achieve the desired colour and crumb structure (EU Freshbake 2009).

In the baking sage, the yeast continues to produce carbon dioxide until the baking process becomes hot (i.e. 55 °C) and kills yeast. More molecules of gas are released into the cells. The extensibility of the cell membranes determines the volume when internal pressure of the cell is increased. As a result of these events, dough expands to increase volume by one-third, which is called oven rise. This is mainly due to the expansion of the gas enclosed in the porous dough structure. The resistance of the dough to an extension and crust formation is a limiting factor for the overall and possible local expansion of the dough/bread (Zhang et al. 2007).

The pore size in the crust may be differed from the crumb. The crust has a denser structure than the crumb. The structure of crust and crumb are very important factors in deterring the quality. The crust is susceptible to the thermomechanical strain and stresses caused by the freezing process. This depends on the hydration of the crust at the end of partial baking (Hamdami et al. 2007). The degree of baking can be a control by the length (or dimension) of the product at the end of baking followed by chilling at room temperature (EU Freshbake 2009).

8.5.2 Cooling or Freezing of Part-Baked Products

Storage life of part-baked products is significantly affected by formulation, processing, packaging and storage conditions (Vulicevica et al. 2004). If the storage time or shelf life is long, part-baked bread has generally to be cooled, pre-chilled, and frozen before storage before transportation to the retail outlet. The pre-chilling and freezing stages are crucial to the retail process (Lucas et al. 2005).

Part-baked breads are generally cooled for short-term storage. The cooling of part-baked products is generally done in a specific tunnel with a refrigeration unit with controlled temperature and humidity. Moisture evaporates from part-baked product during cooling caused evaporative cooling. The evaporative cooling could help to reduce the refrigeration load of the chilling equipment. Water loss during cooling and freezing of part-baked product could be controlled by ambient humidity (Freshbake 2009; Grenier et al. 2002).

Vacuum cooling or chilling can also be applied to part-baked bakery products. Vacuum cooling, a very fast method of cooling, is a convective cooling method that cools the product under partial vacuum with enhanced water evaporation. It reduces the cooling time of any baked product from one or more hours to 2–4 min depending on the performance of the pumping system. However, vacuum chilled part-baked products exhibit higher moisture loss than conventional chilled bread. For this reason, vacuum chilling has a negative effect on the texture of the bread and increases crumb hardness as compared to conventional chilling (Wang and Sun 2001; Le-Bail et al. 2011).

Freezing or frozen storage is a general way to prolong the shelf life of the part-baked bakery by retaining its freshness. Retrogradation of amylopectin in the part-baked dough does not occur during freezing and frozen storage (Barcenasa et al. 2003). Freezing of part-baked products is generally done in blast freezers, individually quick-frozen conveyor freezers and spiral freezers (Stoecker 1998). During chilling and freezing of part-baking process, moisture diffuses from the center of the product towards the crust area due to a large vapor pressure gradient and this causes structural changes. A set point temperature (−25 to −30 °C) of the air in the freezer could be recommended. The products can exit the freezer when the center temperature is at around −15 °C. The frozen product should be placed in plastic pocket to prevent further dehydration during storage (Freshbake 2009). Freezing is not always the best preservation method for partially baked products. The higher specific volume of part-baked produces needs space in the fridge and breaking the cold chain causes irreversible damage to product. In addition, the freezing step is also responsible for flaking. If the part-baked product is not frozen, flaking may occur after the final baking step (http://www.foodtecprovider.com).

8.5.3 Storage of Part-Baked Products

To improve the shelf life of part-baked products and to retard staling, these products are very often cooled, frozen, or deep-frozen. In addition, partial baked products are stored at sub-zero temperatures, positive temperatures and/or under modified

atmosphere until the final baking process is applied. Cold storage of part-baked products can be useful for home consumption and catering because it needs of less energy as compared to the frozen storage. Lainez et al. (2008) reported that part-baked breads stored at 7 °C showed mold growth within a day, while the product stored at 1 °C did not show mold growth until 28 days. The fully-baked bread obtained from part-baked samples stored at 1 °C showed higher values of crumb hardness, and lower sensorial quality as compared to the part-baked samples stored at 7 °C.

In the long-term storage of part-baked products, it is recommended to store the products in frozen condition. This is an effective way to retard staling and prolonging the shelf life of part-baked as well as fully baked bakery products (Samanian et al. 2011). A storage temperature of −20 °C is most commonly used and it is important to freeze the product as quickly as possible before its transfer to the frozen storage. Freezing might induce several problems, such as crust flaking, deterioration in texture of the end products, lowering loaf volume, moisture loss and structural modification of amylopectin (Cauvain and Young 2006).

Crust flaking is one of the major quality problems of this product and it can occur by two mechanisms. These are condensation and freezing of water vapor under the loaf crust during the chilling and the freezing process and product collapses during baking (Le Bail and Ribotta 2005). This problem generally appears during the final baking process. The freezing process is responsible for crust flaking. In fact, such a problem is not mentioned for non-frozen part-baked products. However, crust flakes can form even in the absence of cold storage. Especially chilling condition after partial baking appears to be the most important parameter for the crust flaking. Specific enzymes combined with appropriate processing condition (such as higher air humidity during process, specific cooling, and freezing rate) tend to minimize crust flaking (Ribotta and Le Bail 2007). In general, the extension of frozen storage of the part-baked products causes decrease in the quality of the product after full baking process. These are the loss of moisture, increased crumb hardness and higher staling rate (Barcenas and Rosell 2006a).

Frozen storage of the partially baked product is an expensive process because of the high costs involved in the cold chain. Storage at a positive temperature would decrease the damage caused by ice crystals during freezing. Nevertheless, storage of part-baked products at positive temperatures can cause deteriorations, such as microbes and fungi growth or enzymatic reactions (Barcenas and Rosell 2006b). Therefore, it can be concluded that the use of an antimicrobial agent in part-baked products is very important and, if not, the part-baked breads must be stored at refrigerator temperature or frozen storage (Karaoğlu and Kotancılar 2006).

Freezing and frozen storage are also applied directly to the uncooked dough. However, part-baked products are more favored to the freezing process and frozen storage as compared to raw dough. The dough contains higher level of water and caused higher level of ice crystals during freezing. Repeated freeze-thaw cycles during frozen storage causes physical damage to the gluten protein structure. In addition, this causes weakening of hydrophobic bonds, redistribution of water in the dough gluten network, and loss of retained gas (i.e. poor product volume) (Bhattacharya et al. 2003).

Another storage method used for part-baked products is the modified atmospheric packaging or gas flushing. Modified atmosphere packaging is an alternative approach to chemical preservatives for controlling microbial spoilage in part-baked products. These methods considerably extend shelf life of part-baked products stored at room temperature because of the protective effect of the interior atmosphere of the package against microbial growth. For example, the package of partially baked breads either in a modified atmosphere containing 40 % CO_2 and 60 % N_2, or in polyethylene-polyamide-polyethylene vinyl alcohol bags containing 70 % CO_2, showed longer shelf life. For microbial quality of baked products, hygienic conditions in the bakeries are also important and should be carefully controlled (Bent 1998; Rosell and Gomez 2007).

The glass transition temperature of the bakery products is important in relation to their storage stability. Frozen storage temperature of bakery products should be below the glass transition of product to extend shelf life. For this reason, increased glass transition temperature by applying appropriate processing conditions or optimizations of formulation can improve the storage stability of bakery products (Cauvain 1998; Ronda et al. 2011).

8.5.4 Final Baking of Part Baked Stored Products

The second baking or re-baking stage of part-baked product is compulsory to make its ready for consumption (Karaoğlu and Kotancılar 2006). The final baking of part-baked products is performed for two main purposes: these are the coloration of the crust and the "refreshing" of the firm crumb. The melting of the amylopectincrystallites (forms during storage) occurs at around 40–60 °C caused staling. The melting of amylopectin crystallites can be achieved only if the central section of the crumb reaches the corresponding temperature (around 60 °C). Since this temperature is reached during second cooking, the crumb of re-baked product becomes softer after baking. During the re-baking of frozen products, if heat does not penetrate to the inner parts of crumb, partial refreshment occurs after the second baking. For this reason, frozen part-baked products must be thawed partially or completely by an appropriate method before the second baking. This thawing provides a uniform second baking and facilitates better warming of the inside. In addition, thawing process has a positive effect on crust flaking (Freshbake 2009).

8.6 Quality Improvement Efforts of Part-Baked Products

Different hydrocolloids, such as cellulose derivatives, pectin, and gums, shortening and emulsifiers can improve the quality, stability, and shelf life of part-baked frozen products. These are added to the dough in small amounts. The addition of hydroxypropylmethylcellulose decreases the crumb firmness in both par-baked and

fully baked breads, and promotes the reduction of the amylopectin retrogradation without affecting the sensory attributes. Additionally, hydroxypropylmethylcellulose has a protective effect against the damage promoted by freezing and frozen storage. Different gums affect bread crust differently: guar gum makes the crust softer, xanthan makes it more plastic, and hydroxypropylmethylcellulose makes it firmer and more elastic, while pectin improves the stability of partially baked breads during frozen storage (Barcenas and Rosell 2006b, c; Rosell and Santos 2010; Skara et al. 2013). Sciarini et al. (2012) reported the effects of carboxymethylcellulose and xanthan gum on the quality of part-baked gluten-free bread. During storage at room temperature, hydrocolloids, especially carboxymethylcellulose, have a positive effect on specific volume, crumb hardness and visual images of part-baked bread (i.e. gluten-free). In addition, it was reported that frozen part baked French bread with higher yeast content produced higher specific volume and breads containing vegetable shortening showed lower crumb firmness and chewiness (Carr and Tadini 2003).

Enzymes such as xylanases are widely used in the baking industry to improve dough handling tolerance and the quality of bakery products. It is reported that the addition of xylanase B to formulation of frozen part-baked bread improves the bread quality in terms of specific volume and crumb firmness. In addition, xylanase B significantly diminish the total shrinkage as well as frozen-state shrinkage of the bread crumb when frozen. For this reason, xylanase B can be used for improving the quality of frozen part-baked bread (Jiang et al. 2008).

The quality of part-baked products is significantly affected by processing conditions, such as temperature and time of prebaking, rebaking, chilling, freezing, and storage. For example, the optimum prebaking time is approximately two third of the time required for full baking. However, short prebaking time at high temperature leads to a more open structure of the crumb. In addition, high steam is recommended for improving the crust at the beginning of baking. However, high air humidity during chilling and freezing process tends to minimize the crust flaking. However, a higher temperature of the partially baked bread at the entrance of the freezer seems to enhance the crust flaking phenomenon (Le Bail et al. 2005; Rosell and Gomez 2007).

Hamdami et al. (2007) developed models that may be used to optimize the processing conditions and the combination of the chilling and freezing of partially baked breads. The main results obtained in their study were:

(1) Temperature, velocity and relative humidity of cold air are important. The most influential cold air parameters caused the weight loss, ice concentration in the crumb–crust interface and freezing time.
(2) By using slow freezing in the first stage and fast freezing in the second stage, we can considerably decrease (13.5 %) the ice content in interface in comparison to a single-stage regime. However these can increase the freezing time and weight loss.
(3) Fast freezing should be applied if the objective is to minimize weight loss and freezing time.

The prebaking time of part-baked products before their freezing has a significant effect on their quality after thawing and the final baking. For example, 71 % fraction of baking time for bread prebaking (i.e. prior to freezing and final rebaking after frozen storage) made it possible to obtain a product with sensory and textural qualities close to the fresh bread (Fik and Surowka 2002).

The shelf life of part-baked and fully baked soft bakery products is generally limited by staling, yeast, mold, and bacterial growth. Storage in modified atmosphere has a protective effect, especially against microbial growth. It was reported that packaging of part-baked breads in an atmosphere of 40 % CO_2 and 60 % N_2 and storage at 48 °C inhibits microbial growth for 13 weeks (Leuschner et al. 1999). Doulia et al. (2000) investigated the effect of ethanol content, type of modified atmosphere packaging and ultraviolet (UV) radiation on the shelf life of wrapped part-baked baguettes. These treatments are compared with the conventional chemical preservatives such as calcium propionate and potassium sorbate. They reported, "When ethanol percentage reached 1.5 % by weight in part baked wrapped baguette, the mold free shelf life increased up to 1,050 %. The addition of 0.15 % of calcium propionate or potassium sorbate in dough and applying modified atmosphere packaging and UV radiation treatment of part-baked baguettes increased the shelf life by 1,400, 100, 26 and 106 % respectively."

8.7 Advantages of Part-Baking Process

The major advantage of the par-baked bakery products is its flexibility (i.e. time) to produce a freshly baked product (Lallemand Baking Update 2008). The part-baked products are quickly and easily prepared for consumption and it can be supplied rapid in response to the demand. The main advantages of the part-baking method are: (1) economics, (2) it needs less skilled labour for preparation, (3) it can provide more opportunities in developing diversified products, (4) it can create baked product with fresh aromas, and (5) it can increase profit and can reduce waste. Slightly trained staff can prepare part-baked products on demand using basic equipments such as a proofing cabinet and a simple baking oven (Freshbake 2009). Part-baked products can be widely marketed in different sectors, such as the hotel, restaurant, catering industry and bake-off stations. Especially, these products are suitable for bake-off stations, where products are cooked and served according to customer demand. In addition, part-baking technology enhances the shelf life and availability of some specific bakery products, such as gluten-free bakery products.

Production of part-baked products is not directly dependent on their sales and distribution. The quality of part-baked product can be guaranteed by centralized large scale production. The processes can be standardized in order to produce quality part-baked products. Stock can easily be held and immediate service can be provided in demand. Part-baked products have a short final baking time. Therefore, these products can be sold at any time of the day. The sales forecast is not required

and the risks are minimal at the bake-off points. The part-baked products have the slogan "more fry and ready to service." Because part-baked products are easily prepared, the quality of the final (rebaked) product is better preserved and warranted. The long shelf life of these products allows stocks to be held and it can eliminates under and over stocking. Products in different types and formats can be produced without any extra work. In addition, before final baking stage they can be processed in different types, such as cut in half, filled. The part-baked products can facilitate all day availability of fresh baked products. Consumers can buy a wide variety of part-baked products, and stored them at home. These can be baked in a domestic oven and can be consumed as fresh (Karaoğlu 2006a; http://www.foodtecprovider.com).

8.8 Disadvantages of Part-Baking Process

The main problem in producing part-baked products is the proper control of second baking stage (i.e. optimum time and temperature). If the final baking time is not set well, the product quality can be deteriorated significantly (Lallemand Baking Update 2008). Another major problem for the part-baked bakery product is the formation of crust flaking. The crumb shrinkage arises during chilling and freezing. The frozen superficial crust caused negative (traction) tangential stress and this could explain the crust flaking phenomena (Ribotta and Bail 2007). Crust flaking occurs after the part-baked product is finally baked after storing. Industrial practice suggests that the freezing stage is responsible for this flaking. If the bakery products are not frozen, crust flaking may not occur after the final baking stage. Crust flaking may form even when cold storage is not applied to part-baked products. Adverse storage conditions may magnify the crust flaking but it cannot be considered alone responsible for the flaking phenomena. The main reason for crust flaking is the condensation of water vapor under the loaf crust during the cooling stage. The air humidity level during proving and pre-chilling is shown to be the key factors for controlling the flaking. Low surface hydration levels could reduce crust flaking level (Lucas et al. 2005; Curic et al. 2008; Balestra 2009).

The part-baked products have revolutionized in the restaurant and hotel sector. The consumption of partially baked products at home has not been grown as expected. The consumers are reluctant to switch over oven baking at home. To eliminate this disadvantage, microwavable part-baked products have been developed for home use as well as for some restaurants (http://www.foodtecprovider.com).

The part-baked products are expensive. For partial baking process, products need to be baked twice. Therefore, in the production of part-baked products, energy consumption is greater than that of the conventional process. Part baked frozen technology demands about 2.2 times more energy as compared to the conventional bread making process. It can demand more energy when the freezing process and frozen storage is considered (Le-bail et al. 2010).

8.9 Part-Baked Breads

Two different types of part-baked bread are available. These are part-baked unfrozen and part-baked frozen (Fig. 8.6). Part-baked unfrozen bread is obtained by baking at low temperature without forming much of a crust and almost no crust color. Then, part-baked bread is cooled and stored at to room temperature after packaging. The part-baked breads contain high moisture levels and are not stabilized by a thick crust. Thus these crust tend to wrinkle after baking. The shelf life of this type of part-baked bread is limited because of its high moisture content, The mold growth needs to be prevented using high levels of preservatives and/or applying controlled atmospheric packaging. During the second baking, desired crust color and flavor are generated. In this case the baking time and temperature remain critical (Lallemand Baking Update 2008; Freshbake 2009). After a slowly baking and vacuum cooling are also used to stabilize the intermediate product. Part-baked breads could be distributed and stored at ambient conditions (Stanley et al. 2007). The demand of the unfrozen part-baked bread is increasing since there is no needs of the freezing step (Freshbake 2009).

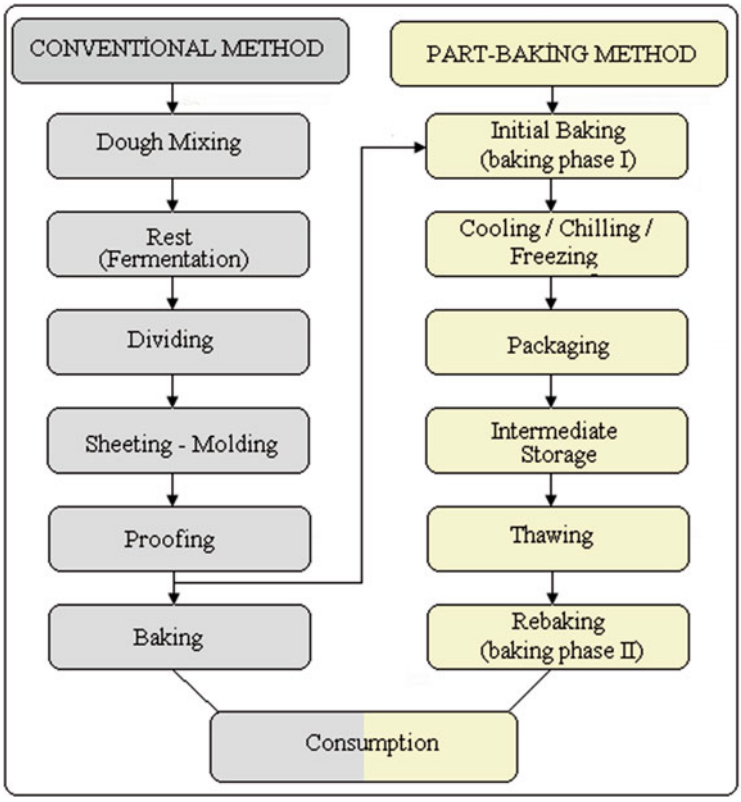

Fig. 8.6 Flow sheet for bread produced conventional and part-baking method

Frozen part-baked is obtained from the unfrozen part-baked thru baking without no crust coloration. Then part-baked bread is cooled and frozen in pack. The control of the partial baking step could be improved by a control of the steaming procedure (Freshbake 2009). Quality characteristics of part-baked bread are its volume, crumb firmness, moisture content, and crust color (Karaoğlu and Kotancılar 2006). Freezing of part-baked bread stops the firming of the bread crumb as well as preserve the crust by preventing moisture migration from crumb to crust. Frozen part-baked bread can be stored in a freezer up to 12 months without microbial spoilage. However, changes in crumb texture can occur after 6 weeks of storage. The frozen part-baked bread after final baking contains a flaky crust, lower volume, denser structure, and harder crumbs as compared to directly baked breads (Skara et al. 2013). The rebaking process will generate and liberate an attractive flavor of freshly baked bread. The lower temperature during the second baking will largely prevent excessive drying out causing rapid firming of the finished product. The major disadvantage of frozen par-baked bread is the high storage cost of the large product volume (Lallemand Baking Update 2008).

The production of frozen dough has increased dramatically in the last few decades due to its demand in producing products by proofing and baking at hot points. However, the frozen dough still needs several requirements associated with wheat flour quality, freezing, and thawing conditions. In recent years, as shown in Fig. 8.7, the number of publications in this field has increased accordingly (Rosell and Gomez 2007).

The initial baking time, temperature, and center temperature of part-baked breads are very important in terms of the final product quality. "High-temperature and short-time" and "low-temperature and long-time" are two basic methods for the initial baking of part-baked bread. The ideal French breads are prepared by two-stage process. For example, in a rack oven, during the first stage, the dough pieces are placed into a steam-filled oven at high temperature for a short time, (i.e. typically 3 min at 270 °C) to open up the cuts. The second phase is a lower temperature baking for a longer time, typically 7 min at 250 °C to ensure the center of the dough pieces into "set bread" (Bent 1998). At the initial baking stage, internal crumb temperature of dough must be above a certain degree in order to avoid shrinkage and collapse during cooling.

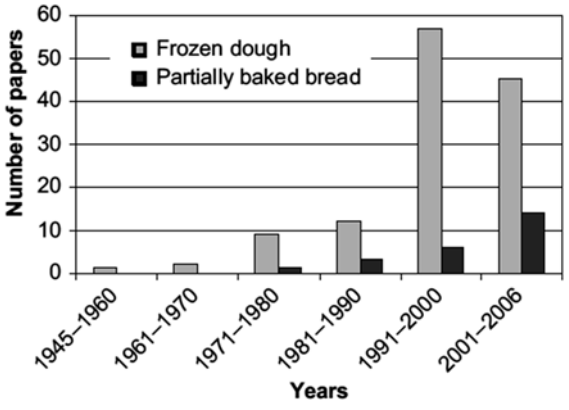

Fig. 8.7 Trend of research manuscripts included in the Science Citation Index related to frozen dough and partially baked bread (Rosell and Gomez 2007)

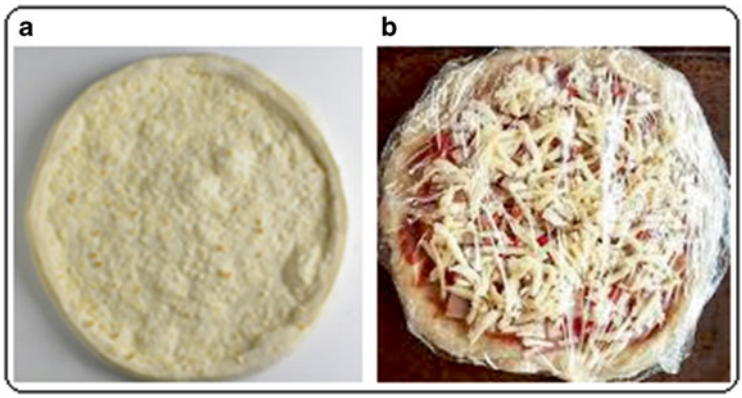

Fig. 8.8 Part-baked pizza crusts (**a**) and complete partially baked pizza (**b**)

8.10 Part-Baked Pizza

Two different types of part-baked pizza are available. These are part-baked pizza crusts and partially baked pizza (Fig. 8.8). Part-baked pizza crusts are prepared for easy application of topping (i.e. easy preparation). In this process, pizza bases (dough) are proofed and partially baked, without any topping on it. The part-baked crust can be stored for 21 days at +5 °C, for 3 months at −18 °C or for 3 months at room temperature in special packaging. When a finished pizza is to be made, the part-baked crust is dressed with sauce, cheeses, and other toppings and then baked. After a few minutes in the oven, the products are ready to eat. These are high quality and delicious (just like freshly baked products) and remain tender for hours. Different types of crusts or whole meal thin pizza or pan pizza, with different toppings, prices, sizes, and formats could be prepared. After part-baking, they are packaged and stored. Part-baked pizzas have a shelf life of 1 month in refrigerated condition or 3 months when frozen (http://www.foodtecprovider.com).

8.11 Part-Baked Cake

Cakes are chemically and mechanically leavened bakery products. High-quality cakes maintain various properties, such as high volume, low cake crumb firmness, and uniform crumb structure. These properties depend on the balanced formulas, aeration of cake batters, and stability of fluid batters in the early stage of baking and thermal-setting stage. Thermal setting of the cake is defined as the batter changes from an emulsion to the porous structure due to starch gelatinization and protein denaturation. During baking, as temperature increases the vapor pressure of water and the rate of formation of carbon dioxide gas increases. This results air bubbles in the expanded cake batter. Further increase in temperature causes starch gelatinization and protein coagulation (Karaoğlu et al. 2008).

Part-baking method or, the two-step baking procedure, can also be used successfully in cake production. For the production of par-baked cake, cake mix or batter is baked at a certain temperature (at around 175–200 °C) for around 15–20 min. Par-baked cakes are cooled by an appropriate method and stored in refrigerator or freezer temperatures until final baking. The cake is not a product of daily consumption, such as bread, so long-term storage of the partially baked cake is necessary and frozen storage could be preferred over room temperature storage. After storage, the par-baked cakes are re-baked until the formation of the desired product structure. Part-baking (initial baking) time should not be very long regarding the cake crumb firmness. On the other hand, the first baking step should not be very short. The short prebaking may cause unstable cake crumb causing volume loss through shrinkage after part-baking stage. The chemical composition influences the quality. Par-bakery products are thus often frozen to delay staling and to prolong the shelf life. The lower storage temperature remarkably reduces the rate of crumb hardening resulted from staling (Karaoğlu et al. 2008; Karaoğlu and Kotancılar 2009).

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Chapter 9
Processing, Quality and Storage of Part-Baked Products

Cristina M. Rosell

9.1 Introduction

Bakery products are the most consumed foods worldwide. There are great differences exist for the types of baked products, depending on raw materials, tradition, processing technologies, and life-style. Bakeries have been responding to the consumers' demands and changes in society, and shift their production processes, products and even distribution channels. Fresh bread as well as other varieties of baked products contained diversified flavours, shapes and sizes. A decade ago, one of the food market drivers was the development of convenience food for satisfying the consumers demand for fresh like products (Rosell 2009). Convenience bakery products are solving the constraints in food preparation and limited time for shopping due to change in lifestyles and due to the increase in the number of women entering in the workforce, fragmentation of the traditional family and growing single-occupancy households.

Traditional baking processes are sometimes too limited and inflexible to fully satisfy manufacturer's requirements and consumer's demands. One of the most significant technological developments in the bakery sector in the last few decades is the development of the technology applied to frozen or low temperature stored products. These products could be easily prepared at home (Rosell and Gomez 2007; Rosell 2009). Bake off technology allows fresh products to be available at any time of the day; it does not require highly trained people, saves costs and ensures a product of uniform quality at any time. In addition, bake off technology has revealed

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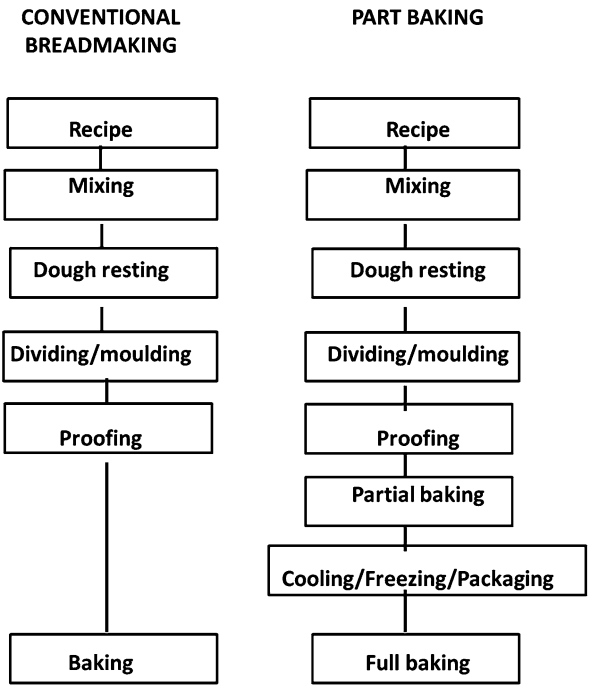

Fig. 9.1 Comparison of conventional and part baking breadmaking stages

as a good method for preventing the staling process and obtaining a product whose quality is close to that of fresh baked products. The main representative of the bake off technology is the partially baked bread, since bread is the most consumed product around the world. This chapter will discuss mainly bread, which is the most common bakery product.

Partially baked product (part-baked, par baked or pre baked) is obtained in two baking stages (Barcenas and Rosell 2006a, b; Fik and Surowka 2002) (Fig. 9.1). First baking gives a product (partially baked bread) with aerated crumb but without crunchy and coloured crust (Fig. 9.2a). During the initial baking the starch is gelatinized and gluten coagulated without completing the reactions (i.e. no crust formation). After that, bread can be stored for extended periods depending on the type of storage selected (refrigerated, frozen or packaged under modified atmosphere or vacuum) (Fig. 9.2b). Second or full baking requires short baking time; it contributes to additional water evaporation from the surface layers, crust development, and allows Maillard reaction (i.e. color formation and development of flavours) (Fig. 9.2c) (Le Bail et al. 2005). The market of partially baked bread has been rapidly growing worldwide because the product is already sized, shaped and partially baked, thus no skilled required for making finished products.

Fig. 9.2 Loaves from different stage of the part baked process (Photo by C.M. Rosell). (**a**) part baked bread, (**b**) part baked bread after frozen storage for 4 weeks, (**c**) full baked breads

9.2 Processing

9.2.1 Understanding Partially Baking Process

Partially baking process has been applied for some decades, but research regarding structural changes occurring during pre-baking, full baking and chilling is dated in the last decade. Barcenas et al. (2003b) simulated the part baking process in the differential scanning calorimeter pans to eliminate the influence of water losses. The differential scanning calorimeter was used as an oven to bake the bread dough inside the capsules, then capsules were kept frozen, and afterward thawed and re-baked. Two endotherms were distinguished in the thermograms when the temperature increased from 25 to 90 °C (part baking), which were assigned to gelatinisation process of the amorphous phase of the starch and to the melting of the more stable crystalline structure of starch second endotherms. During re-baking only one endotherm was observed that corresponded to the melting or fusion endotherm. No retrogradation peak was observed during frozen storage, indicating that no crystallisation of both amylose and amylopectin was produced during that storage.

The behaviour of part baked loaves was studied during part baking, frozen storage and full baking (Barcenas and Rosell 2006b). During those processes, moisture content and hardness of crumb were quantified to determine the impact of temperature changes. The moisture content of the part baked loaves was always higher and the crumb hardness lower than that of the full baked bread, due to the additional evaporation during the full baking and the higher moisture content, respectively. In addition, moisture also decreased during frozen storage owing to a reduction of the water retention capacity of the bread constituents induced by the ice crystals damage. The crumb hardness of the part baked loaves was almost constant during the period of frozen storage. After full baking, a significant effect of the frozen storage was observed on the crumb hardness, with a progressive increase as the frozen storage period was extended. This effect was attributed to the damage of the bread constituents by ice crystal formation with the subsequent breakage of the protein network and leaching out of intracellular amylose. All those effects might increase the interaction between the inter and intra-granular amylose and the formation of a network of amylose that increased the crumb hardness (Barcenas and Rosell 2006b).

Almeida and Chang (2013) reported the changes occurring in the dough after the pre-baking and re-baking steps in the preparation of wheat French rolls, mainly regarding moisture content and starch gelatinization. According to those authors, part baking and full baking did not compromise the moisture content of the crumb. The partial baking was not sufficient to gelatinize completely the starch granules located in the crumb, and gelatinization still proceeded during the full baking. Nevertheless, amylose-lipid complexes were already present in all parts of the rolls after the pre-baking and re-baking steps, as confirmed thermal (calorimetry) and structural (X-ray diffraction) analysis. After partial baking, one important operation is the chilling of the baked product, which has been emphasized as an industrial problem due to the water loss of part-baked bread. The water loss can be prevented by water spraying on the part baked surface without influencing the chilling rate (Monteau et al. 2004).

9.2.2 Formulation

In the case of partially baking processes, formulations or recipes could be identical to the conventional or direct bread making process. Nevertheless, stabilizers of the crumb structure are advisable when part baked products are going to be subjected to freezing and frozen storage. The presence of bread improvers (alpha-amylase, sourdough, hydroxypropylmethylcellulose, kappa-carrageenan) minimizes the negative effect (increase in the retrogradation temperature range) of frozen storage (Barcenas et al. 2003b).

Hydrocolloids are widely used in the food industry due to their capacity to control both the rheology and texture of aqueous systems. In bakery, hydrocolloids have been very useful as bread improvers due to their anti-staling effect (Barcenas et al. 2004).

The addition of hydrophilic gums to the dough recipe has been reported to control ice crystallization and recrystallization to improve the shelf-life stability of frozen partially baked bread. The effectiveness of different hydrocolloids has been studied regarding the stability and the quality of the full baked products. Barcenas et al. (2004) found that κ-carrageenan was not a good improver for the partially baked frozen bread because it has a detrimental effect on partially baked bread kept under frozen conditions. Full baked loaves from partially baked frozen bread containing hydroxypropylmethylcellulose (HPMC) have great specific volume and moisture retention, and in parallel soft crumb and low water activity. Likely, this hydrocolloid inhibits the bread staling during frozen storage (Barcenas et al. 2004). The improved effect of HPMC has been also studied for part baked breads stored at refrigerated temperatures (Barcenas and Rosell 2006a). In fact, its effect has been tested on part baked breads stored frozen (42 days at −25 °C) or refrigerated (10 days at 2 °C). In those studies, the presence of HPMC improved the technological parameters (specific volume, moisture content, width/height ratio, and crumb hardness) and diminished the staling rate without affecting the sensory attributes. The improved effect of HPMC became more evident in part baked breads, which was subjected to frozen storage. This additive protected their microstructure against the ice crystals (Barcenas and Rosell 2006a). Specifically in refrigerated part baked breads, the improved effect of HPMC was observed as a decrease in the crumb hardness in both part baked and full baked breads, and additionally hindered the amylopectin retrogradation.

Vegetable shortening has been added to the frozen French part bread. It was observed that physical and textural characteristics remained similar as fresh one when stored 28 days (Carr and Tadini 2003). The addition of vegetable shortening reduces crumb firmness and chewiness of the full baked bread (Carr and Tadini 2003).

The addition of girasol flour (i.e. 5–20 % of the total mass) has been proposed to improve structure of the frozen par-baked semi-products and to extend their storage life (Ermosh and Berezovikova 2013). The addition of this flour extends storage life of frozen par-baked semi-products up to 120 days, improves the frozen products structure and enhances the baked product quality and its nutritive value. Kang et al. (2012) patented a method for part baked bread utilizing weak flour or medium flour. This bread making method comprised mixing of wheat flour, yeast, sugar, butter and trans glutaminase (0.8 parts by weight, flour basis) to obtain dough. The process included molding, partial baking and finally freezing the part baked bread. Other enzymes that could be added included Fungamyl Super MA, Novamyl 10.00 BG, Novamyl 1500 MG or ascorbic acid.

Specific enzymes are recommended for this type of products, like a fungal and amylase type enzyme, which was launched by Puratos in 2010 (Bouckley 2010). The objective was to replace chemicals in the production of frozen part baked products. The addition of fungal phytase has been also recommended for making partially baked wholemeal bread. This can improve the nutritional contents and decrease the phytate content in the full baked wholemeal breads (Rosell et al. 2009). The combination of fungal phytase and frozen storage could be advisable for overcoming the detrimental effect of bran on the mineral bioavailability in the case

of wholemeal breads (Rosell et al. 2009). A blend of improvers containing acid ascorbic, alpha-amylase, protease and hemicellulase has been proposed for extending stability of frozen part baked breads (Ribotta and Le Bail 2007).

Part baking technology has not been immune to the current nutritional trends in bakery products. In fact, different formulations have been proposed for improving the nutritional pattern of these products, although the structural effects on crumb must be assessed. Dietary fibres have been the most often added ingredient. Despite the increasing awareness on the beneficial awareness of fibre enriched bakery products, a few researches have been focussed on the technological impact (i.e. baking time, low baking temperatures and low or sub-zero storage) of those ingredients on partially baked products. It is already established that all polymeric compounds that interact with water can affect the quality of the final product (Jinshui et al. 2002).

A study carried out by Rosell and Santos (2010) compared the technological functionality of different fibres (high methylated ester pectin, resistant starch, and insoluble-soluble fibre) in partially baked breads, which could be stored either sub-zero or low temperatures. Fiber-containing formulations affected bread specific volume and crumb hardness, and those characteristics were also dependent on both the bread making process (conventional or part baking) and the storage conditions of the par-baked bread (low or sub-zero temperatures). Particularly, the technological functionality of pectin was negatively affected by partial baking and partially baked breads. The bread containing fibre did not show enough strength for keeping its crumb structure during storage. Moreover, inclusion of resistant starch and fibre in the bread formulation induced a reduction in the specific volume and an increase of crumb hardness (Rosell and Santos 2010).

At this point, it is important to remark that fibres addition to part baked bread has promoted a significant effect on the glycaemic index. Borczak et al. (2012) investigated the effect of 10 % addition of dietary fibre (oat fibre 75 % and inulin 25 %) to partially baked frozen wheat rolls on the glycaemic index considering 15 healthy humans volunteers. The authors concluded that frozen storage of part baked breads combined with fibre addition significantly reduced (i.e. 35 %) the glycaemic index (Borczak et al. 2012). Similarly, other nutritional effects have been reported for the frozen stored part baked breads with the addition of fibres (Kopec et al. 2011). Studies also carried to assess the biological value of proteins, lipid profile, and some minerals content of frozen part baked breads on selected tissues of rats (Kopec et al. 2011). Part baked breads, with or without fibre enrichment, showed significantly higher chemical score and essential amino acid index when compared with the conventional bread. Part baking also improved protein digestibility, however digestibility decreased with the addition of fibre. Ronda et al. (2012) studied the effect of rapidly digestible starch (RDS) and slowly digestible starch (SDS) in the wheat breads prepared from frozen partially baked breads contained different types and levels of fibres. The addition of fibres like inulin or wheat bran increased the starch digestive index (Ronda et al. 2012).

Different dietary fibres, such as resistant starch, locust bean gum and wheat bran have been used to obtain partially baked bread (Almeida et al. 2013). It has been recently reported that fibres do not affect the specific volume and crumb texture of

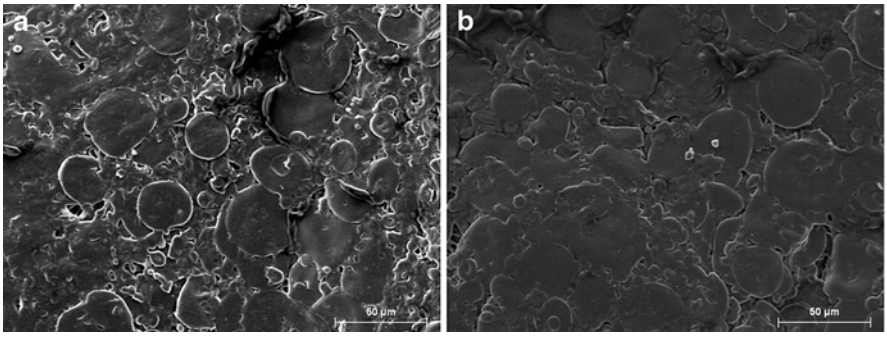

Fig. 9.3 Scanning electron micrographs of bread crust surface. Images correspond to the following enzyme treatments: (**a**) no enzyme treatment, (**b**) amyloglucosidase (200 mg/100 mL). Scale bars of 50 µm

part-baked bread, as usually happens in conventional bread making. This could be due to their possible masking during freezing and frozen storage. The resistant starch and locust bean gum contributed to retain moisture content of the crumb, whereas wheat bran showed higher scores in the sensory evaluation. Almeida et al. (2013) concluded that dietary fibre can be used for improving technological characteristics of part baked breads in addition to their nutritional importance.

Crispness is among the most important factors that the consumer uses to assess the quality of crispy bread, but it is rapidly lost after baking; and this drop is even more noticed in the part baked breads. Some fundamental studies revealed that crispness sensations involve numerous physical parameters, combining molecular, structural, and manufacturing process (Roudaut et al. 2002). Crispy bread crust is originated when starch and gluten matrix are in glassy state and it has been associated with low moisture content or low water activity (Stokes and Donald 2000). Crispness retention can be increased by enhancing the water vapour permeability of the crust (Hamer and Primo-Martin 2011). Therefore, creation of cracks on the crust surface after baking could increase water vapour permeability and therefore improved crispness (Hirte et al. 2013). Recently it has been reported that crusts matrix with high in gelatinized starch with poor distribution of gluten showed higher tendency to crack at end of the process of part-baking, freezing, and full baking (Hirte et al. 2013). Cracks favour water vapour permeability of the crust and subsequently instrument to the crispness. Hamer and Primo-Martin (2006) presented an innovative way for preparing a part baked bread, which retained its crispy crust during storage. The proposed method consisted mixing flour, water and other bakery ingredients to form bread dough. In addition they applied an enzyme with proteolytic activity on the outside surface of the part baked bread. The baked bread obtained with this treatment will retain a crispy crust for a considerable period of time after baking. Recently, Altamirano-Fortoul et al. (2014) proposed the spraying of amyloglucosidase on the surface of part baked breads for changing their mechanical properties of crust. In this way, major amount of starch is hydrolysed and a smooth layer is achieved (Fig. 9.3). However, high levels of enzymes caused fragility

of the crust, which was observed from the lower rupture force. Crust microstructure analysis confirmed that enzymatic treatment caused changes in the bread crust structure, leading to a disruption of the structure (i.e. high voids) by removing the starchy layer (Altamirano-Fortoul et al. 2014).

9.2.3 Equipment

The production of par-baked breads requires some modification of the bread making lines, particularly in baking, cooling and freezing (Rosell 2009). The main difference between conventional and part-bread is their baking process. Part baking objective is to form the crumb structure and this is achieved by lower oven temperature or baking time. Tunnel ovens are the most common for making part-baked breads. The vertical ovens use less floor space and their compact structure minimizes the amount of steam necessary for a thin and soft crust. The amount of steam is decisive, since this may cause drying of products completely, and the crust can be detached during the second baking (Rosell 2009).

Nevertheless, several studies were conducted for assessing the effect of proofing (Le Bail et al. 2005), partial baking (Fik and Surowka 2002; Barcenas et al. 2003a), chilling and freezing conditions (Barcenas and Rosell 2006a, b) on bread quality. Baking duration and oven temperature in the two steps of baking are crucial. Baking time of 71 % as compared to the conventional baking time produces breads with good stability during frozen storage and acceptable sensory features for a storage period of 11 weeks. However, lower baking times always do not ensure desirable sensory and textural features of bread after its frozen storage and re-baking (Fik and Surowka 2002). In general, optimum time for the initial partial baking is advised within the range from 74 to 86 % of the time needed for the full-baking in conventional bread making (Fik and Surowka 2002). The selection of the adequate time for the first step baking is fundamental because it affects the crumb softness and the hardening rate during aging (Karaoglu 2006). Considering the crumb softness, it is advisable a short initial baking time or long re-baking time in the case of wheat bran bread (Karaoglu 2006).

In the case of part baking (i.e. French style), a specific study on the time and temperature for the partial baking, thawing and second baking was carried out by Park and Baik (2007). Part baked bread with similar loaf volume and crumb structure as full baked bread required 6 min baking at 218 °C (i.e. core crumb temperature 97 °C). If lower baking temperatures are used, an adjustment of increased baking time is necessary. The second baking should be extended until 12 min for frozen part baked bread. The thawing time of 180 min need to be used in order to produce a crust colour, crumb moisture, and hardness, which could be comparable to the conventional process. When excluding thawing, the second baking time should be extended to 16 min in order to obtain similar crust colour, although the crumb of the loaves contain higher moisture content. Lower initial baking temperature during the partial baking led to softer breads after the second baking

(Park and Baik 2007). In any case, it must be taken into account that freezing, thawing and second baking decrease the loaf volume.

Chilling of the part baked bread under desired conditions is also fundamental to obtain good quality products. Some modifications are necessary during the cooling of these products. Part baked breads should be cooled to room temperature after baking and before entering the freezer, when storage is made at sub-zero temperatures. Too warm core temperature generates a dry shell that will flake off later, and also supplemental energy and more time will be necessary to freeze the breads (Rosell 2009). Humidity of the ambient air is a key factor, because humid air blown over the bread to cool may enhance the mould growth on the surface of part baked products.

One of the quality problems of the fresh bread obtained from partially baked bread is the crust flaking resulted from the detachment of some part of the crust. Le Bail et al. (2005) reported that chilling conditions after partial baking are the most determinant parameters on the crust flaking as well as the proofing conditions. In general, high air humidity during the processes tends to reduce crust flaking. A study was carried to determine the impact of the chilling condition after partial baking (50–55 % and 90–95 % air humidity at 20 °C) and freezing condition (blast air freezer with the bread centre temperature at the entrance in the freezer of 35, 45 or 55 °C) (Le Bail et al. 2005). This study concluded that high temperature of the partially baked bread at the entrance of the freezer (55 °C vs. 35 °C) enhanced the crust flaking phenomenon.

A microstructural study on the pre-chilling and freezing of part-baked bread was conducted by Lucas et al. (2005) using magnetic resonance imaging (MRI). The MRI signal displayed a constant intensity under the upper crust, except in the case of certain voxels where an increase in signal intensity of varying magnitude was observed. This corresponded to loaf collapse and subsequent densification of the crumb, and the decreased MRI signal in all voxels due to water crystallization. During prolonged storage, no changes in the dry matter measurements and the MRI signal intensity were observed. This confirmed the non-existence of vapour condensation on cooling. Authors related these results with the susceptibility of the part baked bread to flaking (i.e. response to deform due to the compression of the gas phase on cooling). In consequently, loaves with a lower level of deformation were most susceptible to flaking (Lucas et al. 2005). Another alternative is the use of vacuum cooler to stabilize the crusty part baked structure without producing wrinkling or shrivelling of the loaf during storage at ambient temperature. This bakery equipment allows cooling down bakery products simultaneously the outside and inside parts, preventing water migration. Cooling with this system often increases the volume and stability of the bread.

Considering that bread baking is one of the most energy demanding processes (around 4 MJ/kg), it is important to determine the efficiency of the process of the part baking or bake off technology. Le-Bail et al. (2010) compared the energy demand for crispy rolls produced by conventional baking process or part baked frozen process. These authors pointed out that pre-heating of the oven requires a significant energy demand, and then during baking 15–20 % of the total energy is

used for heating up the dough and 10–20 % for crust drying. Other considerations included: partial baking requires two stages baking, and the energy demand might be supplemented with the energy required for freezing. Globally, part baked frozen technology demands about 2.2 times as much energy as conventional bread making process (Le-Bail et al. 2010).

The hygienic conditions in the bakeries should be carefully controlled, because microorganisms do not grow at frozen temperatures but the final baking is not sufficient to inactivate microorganisms, particularly *B. licheniformis* spores (Leuschner et al. 1998).

9.3 Storage

9.3.1 Physico-Chemical Changes During Storage

Partially baked products can suffer microbial spoilage very rapidly owing to its high moisture content. *Pichia anomala, Hyphopichia burtonii* and *Saccharomycopsis fibuligera* are spoilage yeasts causing chalk mould defects on part baked breads. A study carried out by Karaoglu et al. (2005) showed that microorganism counts increased significantly when part baked breads were stored at 20 °C (room temperature) for 3, 5, and 7 days, and the second baking contributed to the re-freshness of breads and decreased the microorganism counts. The levels of water activity for full baked breads (ranged from 0.92 to 0.89) did not significantly affect the microorganism counts. However, addition of calcium propionate in the bread formulation significantly decreased total aerobic mesophylic bacteria, coliform bacteria, Bacillus spore, yeast and mould counts, although the extent of reduction depended on the pH levels (Karaoglu et al. 2005).

Freezing, frozen storage, thawing and re-baking expose bread matrixes to thermal shocks and this can change physico-chemical properties of the full baked products. Part baked bread can be stored under frozen or low temperature conditions. The use of refrigerated condition or positive temperature storage can extend the shelf life of partially baked bread. This storage conditions do not modify the microstructure of the bread crumb. Part baked loaves stored at low temperatures show progressive crumb hardening and rapid crystallization of the amylopectin chains, but the heat applied during full baking process can reverse those processes, although the degree of recovery is directly related to the duration of the storage (Barcenas and Rosell 2007). Part baked breads stored at low temperatures led to breads with better specific volume, low crumb hardness and slower hardening rate during staling than those obtained from frozen part baked ones (Barcenas and Rosell 2007). In addition, loaves from refrigerated part baked breads keep appearance and aroma, but lower scores in taste and texture were reported as compared to the breads from frozen partbaked breads.

Barcenas et al. (2003a) reported that no retrogradation of amylopectin was detected in the partbaked bread during frozen storage. But when moisture content and crumb hardness were recorded in the part baked bread after 7, 14, 28 and 42 days of

frozen storage at −25 °C, hardness remained constant while the moisture content decreased with the time of frozen storage (Barcenas and Rosell 2006b). Nevertheless, aging studies of full baked bread showed progressive increase in the retrogradation in amylopectin, and great energy was required for amylopectin melting at longer frozen storage period. Simultaneously, crumb hardness of the full baked bread increased with the time of frozen storage, while moisture content of the crumb decreased. Also the hardening rate during aging was dependent on the time of frozen storage (Barcenas et al. 2003a; Karaoglu 2006). Therefore, some structural changes are produced during the frozen storage that affect the final quality of the full baked product. Those changes have been associated to the damage of bread structures produced by the ice crystallization. This was supported by the results of cryo-scanning electron micrographs (Barcenas and Rosell 2006b). Alpha-amylase, sourdough and HPMC have been proposed as bread improvers because they decreased the retrogradation enthalpy of the amylopectin, retarding the staling (Barcenas et al. 2003b). Some deep modification at molecular level, for instance on starch chains arrangement, has been observed on scanning electron micrographs (Barcenas and Rosell 2006b). Indeed, a significant increase of resistant starch in frozen stored part baked wheat rolls was observed by Borczak et al. (2008). This could subsequently reduce the glycaemic index. The low glycaemic index diets have been associated to reduce the insulin resistance syndrome, cardiovascular disease, type 2 diabetes and certain cancers (Holm and Björck 1992). Any strategy to decrease the glycaemic index of the bakery products is welcomed.

Hamdami et al. (2004) simulated the freezing process in an infinite two-layer cylinder to understand the phenomena governing the heat and mass transfers during the freezing of par-baked bread. The model considered the apparent specific heat, enthalpy, thermal conductivity, and water activity, and predicted the temperature profiles and weight losses. They also validated the freezing of par-backed breads with cylindrical shape.

Freezing and frozen storage provoke a retraction of part-baked bread derived from the contraction stress in the matrix during the freezing process due to a rapid deformation during ice-crystallization (Ribotta and Le Bail 2007). Those changes affect water properties and modify the shrinkage tendency of part baked crumb (Ribotta and Le Bail 2007).

Crust flaking has been related to excessive drying of the bread surface at the end of the post-baking chilling and freezing process (Lucas et al. 2005). Crust flaking is produced due to the concentration of ice below the crust during freezing and the mechanical damages induced by the thermo-mechanical shock during chilling, freezing and final baking (Hamdami et al. 2007). Specifically, the thermal stress induced by the volume expansion of water during freezing process of part-baked bread has a great impact on flaking. Consequently, it is very important to understand the thermo-mechanical changes associated to freezing in order to control and prevent strains within the loaf. Expansion due to phase change and thermal contraction play a fundamental role to explain cracking patterns (Ben Aissa et al. 2008). During freezing, cracking is likely due to tensile tangential stresses caused by thermal contraction. Presumably, vitrification at the surface induces crack initiation and this could propagate towards the centre (Ben Aissa et al. 2008).

9.3.2 Industrial Storage

Partially baked bread has high moisture content, thus storage conditions must be used to prevent mould contamination. Low or sub-zero temperatures are the most common alternative for keeping part baked products at industrial level. Part baked breads should be about 90 % frozen when they exit the freezer. Long freezing time could produce freezer burns, whereas inadequate frozen time could collapse the products (Rosell 2009). Another consideration to remain frozen until its full baking, since partially thaws and then refreezes affect the quality of part-baked breads.

Freezing conditions can influence frozen part baked bread quality, because an excessive drying of the surface might be responsible for crust flaking and cloudy colour of the crust. The formation of ice crystals below the crust during freezing will induce the flaking of the crust. Hamdami et al. (2007) proposed a two-stage freezing process with controlled changes of air temperature and air velocity during the two stages. Measurements of the weight loss, ice concentration at the crumb-crust interface and freezing time allowed to identify optimal process conditions. Authors' findings advised a rapid freezing (5 m/s and 233 K) to minimize the weight loss and the freezing time. Conversely, slow freezing (0.5 m/s and 253 K) at the beginning of the freezing process would be recommended to minimize the ice content at the crust-crumb interface, and subsequently to prevent flaking. Overall, it is suggested a slow freezing (0.5 m/s and 253 K) in the first stage followed by a rapid freezing during the second step (0.5 m/s and 233 K).

Studies have been also carried for other bakery products like cup cakes (Karaoglu et al. 2008). A systematic study regarding the effect of partial baking time (15, 20 or 25 min at 175 ° C), frozen storage time (3, 6 or 9 months at −18 °C) and second baking time (10, 15, or 20 min at 175 ° C) on baking loss, volume, moisture, colour and textural properties of cake was carried out by Karaoglu et al. (2008). Baking loss, moisture content, colour, firmness, gumminess and chewiness of the full-baked cakes were significantly affected by part baking as well as frozen storage time. Longer par-baking led to a decrease in the baking loss and an increase in the moisture content in cake. Conversely, specific volume, cohesiveness, springiness and resilience were significantly worsened when increasing the frozen storage time. Considering overall quality of the part-baking cup cakes, the conditions should be 20 min initial baking time and 3-month intermediate storage at −18 °C (Karaoglu et al. 2008). Similarly, the effect of part baked cake storage at refrigerator temperature (4 °C) for 30, 60 and 90 days was reported (Karaoglu and Kotancilar 2009). Firmer cakes with less cohesive and lower specific volume as well as moisture content were observed with increasing refrigerated storage time.

Some specialties like brown soda bread, which has a pH of 7–9, need special attention. Leuschner et al. (1998) reported that brown soda part-bread developed ropiness after two days storage at room temperature due to the retained active spores of *Bacillus subtilis, B. pumilus* and *B. licheniformis* in partial baking. Those authors observed that re-baking of the part baked bread activated particularly *B. licheniformis* spores.

9.3.3 Consumer Retail: Packaging

The most usual method for storing the part-baked bread was freezing. The freezing is generally carried out in industrial bakeries and products are kept frozen until its distribution to retailers. However, lately the ambient part-bake category is also emerging. Market research indicated that in UK this type is growing 1.8 % per year.

In this picture, packaging characteristics are rather important to keep the properties of the part baked product. The packaging barrier properties might affect the phenolic and phytosterol content, oxidative stability and crumb texture of part-baked. A study carried out by Novotni et al. (2011) tested different materials, like blue coloured high density polyethylene (PE-HD) and transparent polyester-polyethylene-ethylene-vinyl alcohol copolymer (PET-PE/EVAL/PE). The part-baked breads stored at −18 °C using above plastics showed that their oxygen permeability did not change during storage. During frozen storage of part-baked total phenolic content and oxidative stability decreased. Oxidative stability of bread in PE-HD package was better than in PET-PE/EVAL/PE due to their blue colour and lower light transparency. Neither total sterol content nor crumb firmness depended on the packaging material (Novotni et al. 2011).

In 1983, AlbroBakkerijen BV presented a process of extending shelf life of partly baked products. In this process air was evacuated and a protective gas (e.g. carbon dioxide with or without nitrogen) inserted in a sealed pack containing part-bake bread. The gas mixture of nitrogen and carbon dioxide is used to prevent spoilage and retained fresh characteristics. Bread must be inserted into the pack immediately after baking (i.e. whilst still hot) and is cooled by subsequent evacuation. Later, a method of packaging for hot part baked breads from oven into a gas-barrier package under a preservative gas was presented. This process was carried in-line while products were hot (Deighton et al. 2003). This method was considered as modified atmosphere packaging and this are being used extensively for storing part baked bread at ambient temperature. The fungi static and bacteriostatic action of the carbon dioxide besides the low levels of oxygen (<1 %) ensures the inhibition of moulds and other aerobic spoilage organisms. In addition bread staling is retarded owing to the hindering effect of carbon dioxide on the starch retrogradation. The most commonly used levels of carbon dioxide and nitrogen are 60 and 40 %, respectively (Galic et al. 2009; Leuschner et al. 1999) or 70 % carbon dioxide in polyethylene-polyamide-polyethylene vinyl alcohol bags (Doulia et al. 2000). Under those conditions the shelf life of the part baked bread might be extended more than 2 weeks. Nevertheless, the level of carbon dioxide can rise up to 100 % in some specific type of bakery products (Galic et al. 2009). For instance, brown soda bread packed in an atmosphere of 40 % CO_2 and 60 % N_2 and storage at 4 °C can avoid microbial growth for 13 weeks (Leuschner et al. 1999).

Effectiveness of the modified atmosphere packaging against microbial growth sometimes is not sufficient, and some forms of spoilage organisms can grow during summer months. In fact, Deschuyffeleer et al. (2011) analysed spoiled part baked breads packaged under a low oxygen and high carbon dioxide atmosphere and

identified *Pichiaanomala* as the main spoilage microorganism and only 5 % of the yeast were identified as *Saccharomycopsis fibuligera.* In order to develop adequate strategies of conservation, these authors studied the lag phase and growth rate of these yeasts under different conditions of pH (2.8–8.0) and water activity (0.88–0.98). *P. anomala* was able to grow in the whole range of pH, but *S. fibuligera* showed a pH optimum of 5. The optimum water activity for growth ranged from 0.96 to 0.98 (Deschuyffeleer et al. 2011). These results indicated that solely modified atmosphere packaging is not sufficient to inhibit all forms of spoilage microorganisms and consequently it does not extend the shelf life of part-baked bread more than 3 weeks. Therefore, complementary conservation strategies are necessary to guarantee the shelf life of part baked products for maintaining their quality.

Similarly, it was proposed the packing of part baked bread under partial vacuum into hermetically sealed packages and sterilized in the hermetic packages during the enclosure (Joulin 1982). This product can be stored at ambient temperature without deterioration.

Part baked products require to be opened from the plastic packaging and then it needs to transfer into the oven for baking. A packaging invention was presented by Eul & Guenther (2006) to avoid the direct contact of the baked goods to avoid pathogen contamination during catering in the railways or airlines. This packaging system has a double layer wrapper with an outer printed layer and an inner sealed layer. This could be used for a short baking cycle and the vent holes in the package open under the excess of inner pressure created during baking.

In addition, part baked products have been also adapted to automatic vending machines. Hecht and Bir (2002) patented a vending machine that consists of a cold chamber to keep part baked baguettes, a vertical conveyor to transfer them to an oven, and a storage chamber from which baked breads are transported to an outlet accessible to the customer. The machine is programmed to supply ready-baked bread to meet sales requirements at various times of the day and night.

A common household practice is the microwave re-heating of part baked breads, which offers an opportunity to supply fresh baked goods with a simple baking at any time or even at retail locations. However, re-heating conditions might affect texture of part baked products, particularly reduction of porosity and crust softening. Therefore, the optimization or adaptation of formulations must be considered to reduce microwave induced toughning of re-heated bread.

9.4 Quality of Full Baked Products

Very often the full baked products obtained from partially baked ones showed lower quality than their homologous obtained from conventional breadmaking, although limited information is available. During storage of frozen part baked breads for a prolonged period of time, bread quality may undergo changes, such as increased firmness, moisture and flavour losses. In addition, breads from frozen partially baked bread are particularly sensitive tocrispiness of the crust. Crust characteristics

are decisive for the purchasing (Lambert et al. 2009). Crispiness is a complex attribute resulting from multiple sensations and influenced by numerous physical parameters (molecular structure and processing condition).

In 2006, Carr et al. (2006) compared the quality of breads obtained from conventional bread (i.e. full baked breads) obtained from part baked breads and stored at −18 °C for 7 days. Their findings confirmed that weight and specific volume of frozen part-baked bread were significantly different ($P<0.05$) than the fresh bread. Frozen storage favours the appearance of large pores in the crumb microstructure (Polaki et al. 2010). Sensory analysis, carried out by trained judges scored differences for appearance, tactile by direct touch and mouthfeel (Carr et al. 2006). Although consumer acceptance test developed for evaluating appearance (i.e. gloss, roughness and cut on bread surface), mouthfeel texture (i.e. crust crispness and crumb firmness) and overall flavour indicated that 4-day frozen part-baked scored higher than the bread from conventional breads (Carr et al. 2006).

The effect of different breadmaking processes (conventional, frozen dough, frozen partially baked bread) and the effect of the storage period on the technological quality of fresh wholemeal wheat breads was reported by Rosell et al. (2009). Their results confirmed that breadmaking technology significantly affected the quality parameters of wholemeal breads (specific volume, moisture content, crumb and crust colour, crumb texture and crust flaking). In addition, frozen storage affected the quality of the loaves obtained from partially baked breads, principally crust flaking. The major quality problems is crust flaking (Hamdami et al. 2007).

The impact of frozen storage on the quality of the full baked bread has been assessed in different bread specialties. Vulicevic et al. (2004) reported the behaviour of four part baked breads (specific variety, white, multi-grain and rye) along storage at −18 °C for 9 months. The sensory, chemical and physical attributes and properties allowed to determine the storage life and also to develop a prediction model based on the bread quality (i.e. rejected quality level based on sensory perception) (Vulicevic et al. 2004).

Altamirano-Fortoul and Rosell (2011) determined the quality of several loaves specialties from frozen partially baked breads. Quality assessment included parameters that characterize bread crust and crumb, and instrumental values were in the range reported for wheat breads. In that study, crust flaking hardly represented a problem, although crust mechanical (crispness) properties were rapidly lost during the first 4 h baking. This was due to the increased water activity (from 0.50 to 0.74) and moisture content (from 9 up to 15 g/100 g).

The technology of the partial baking and frozen has been also applied to other bread specialties like flat breads, widely consumed in Asian countries. Flatbread is characterized by a large rounded surface and a very thin crumb. Generally, this type of breads is consumed fresh, and lately strategies for extending their shelf include the addition of preservatives and the use of part baking. The special characteristics of this type of breads, with a tiny crumb, require a specific analysis. Chapatti bread is flat and chemically leavened bread. This type of bread stales very rapidly losing around 60 % of its extensibility after 24 h of storage at room temperature (Gujral et al. 2008). Part baked chapatti allows reducing the extensibility loss (only 3.7 %

after storage of 24 h). Frozen storage of the part baked chapatties is an effective option for retarding staling, since after thawing and rebaking chapatties exhibit texture equivalent to that of conventionally baked chapatties (Gujral et al. 2008).

Barbari is one of the flat bread specialties consumed in Iran, Turkey, and some Arab countries. Majzoobi et al. (2011) investigated the quality of part baked and part baked frozen Barbarito preserve the quality of Barbari bread for longer time and to delay its staling. Part baked Barbari had higher moisture content, which was responsible of the short shelf life (72 h), but quality was fully recovered after full baking. However, when storing under frozen conditions it was possible to extend the shelf life of Barbari up to 2 months. In addition, full baking was able to overcome the adverse effects of growth of ice crystals during freezing, although a reduction in bread volume was observed (Majzoobi et al. 2011). Their microstructural studies showed that the crumb of Barbari bread was fully formed after part baking, thus staling started after that stage, and full baking allowed obtaining bread with soft texture, and adequate colour, taste and flavour. The reduction in bread volume after full-baking was barely detected by consumers owing to its flat shape (Majzoobi et al. 2011).

Very often part baked flat breads are re-heated in microwaves before consumption, but that practice requires to adapt the formulation for reducing the texture stiffness. The substitution of 20 % of wheat flour with soy blends has been recommended to obtain softer and less chewy texture. This was due to the action of soy lipids (Serventi et al. 2011). Proton nuclear magnetic resonance relaxation tests confirm that soy blends change the water dynamics leading to a more solid-like matrix due to the high hygroscopic properties of soy protein and the plasticizing effects of the lipids (Serventi et al. 2011). These analysis also suggest that soy addition increases mobility of the water. Thus, soy addition affects the texture and water properties of part baked flat bread and these are more stable during frozen storage (Simmons et al. 2012).

As it has been mentioned before, sometimes refrigeration is preferred for keeping the part baked breads and quality might be superior to as compared to conventional ones. Karaoglu (2006) found that re-baked bran bread stored for 7 and 14 days at refrigerator temperature gave softer crumb than the bread obtained by conventional process. However, quality differences have been found even within the temperature of refrigeration (Lainez et al. 2008). In fact, partially baked bread stored at 1 °C can be stored for 28 days without showing microbial growth; in opposition, if the storage is carried out at 7 °C part baked breads show mould growth after 9-days (Lainez et al. 2008). Despite that microbiological shelf life can be extended when stored is carried out at 1 °C, the quality of the full baked bread is strongly affected, because lower temperatures induces high hardness and from the sensory point of view breads obtain lower scores (Lainez et al. 2008).

Fibers or hydrocolloids affect the microstructure of the crumb leading to changes in the pore roundness and pore size distribution. This was observed in the crumbs analyzed by digital image analysis and scanning electron microscopy (Polaki et al. 2010). Pore roundness has been correlated to organoleptic attributes such as aroma and adhesiveness. At microstructural level the status of carbohydrates (fibrous, soluble,

particulate or colloidal form) can affect the final microstructure and consequently the stability of the part baked breads during storage (Polaki et al. 2010).

Part baking technology has been very successful for providing gluten-free bread with better quality, since this type of bakery products have very short shelf-life. Novotni et al. (2012) found that partially baked frozen technology can improve quality and shelf-life of gluten-free bread, and when more than 15 % sourdough was included in the formulation the specific volume increased, crumb firmness decreased and firming was delayed. Therefore, the combination of sourdough and partially baked frozen technology can improve quality and shelf-life of gluten-free bread and in addition a decrease in the glycaemic index is obtained (Novotni et al. 2012).

Acceptable quality was observed when gluten free part baked breads were stored under refrigerated conditions for 7 days (Sciarini et al. 2012). Precisely, partbaked gluten free breads have lower specific volume and higher crumb hardness due to the rapid amylopectin recrystallization. However these characteristics did not change further during cold storage. The addition of hydrocolloids in the formulation of gluten free breads can alleviate the crumb hardening during the cold storage. Moreover, carboxymethylcellulose produced more homogeneous crumb structure (Sciarini et al. 2012).

9.5 Future Prospects

Part baking process allows to produce loaves ready to sell after a short baking. If the process and storage is conducted in adequate conditions, the quality of the full baked products is highly acceptable with similar to the conventional breads. During the last decades, the market of the part bakery products has experienced an exponential growth mainly in the Western countries due to change in their life-style. However, the same trend is foresighted in Eastern countries during the coming years. This could force to introduce different types of part breads. In addition, this part breadmaking technology could be very useful for the production of bakery products suitable to the specific populations, for example gluten free breads.

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Chapter 10
Minimally Processed Meat and Fish Products

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10.1 Introduction

Modern society concerns on the nutrition and the roles of foods for maintaining and improving human health and well-being (Gilbert 2000). The increased consumers' demand for quality, variety and convenience has triggered the development of many new products. However, food safety and quality are the top priorities to the authorities and consumers worldwide. As far as muscle foods are concerned, consumers look for high quality and convenient meat and fish products containing natural flavour, fresh appearance and nutrients. Additionally, safe and natural products without additives such as preservatives and humectants are being demanded (Hugas et al. 2002). The production and processing of meat and fish products without compromising safety and quality, is stimulating a major research issue to develop and implement alternative technologies such as minimal processing (Aymerich et al. 2008). Moreover, there is a need of developing gentle treatments for foods. In additions, more functional foods and nutraceuticals considering health aspects are being emerged.

The processing of muscle foods through conventional techniques incurs substantial losses of various vital nutrients. The main reason for these losses is due to extreme treatment with a longer period of time to achieve food safety. The complex composition of meat and seafood and their variety requires highly efficient processing techniques with enough flexibility. Despite the extensive knowledge in food

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preservation by heat treatment and continued attempts to improve the quality of processed foods, there is still a need in developing new technologies. The current chapter deals with various minimal processing approaches used in meat and fish products and their influences on the functional and nutritional qualities.

10.2 Minimal Processing

Nowadays consumers are consistently striving to get meat and fish products that are fresh and natural as well as safe to consume. In order to meet this demand, a new and promising approach of processing has emerged, minimal processing. The concept of minimal processing is however ambiguous and misleading. It usually involves substantial processing of foods with fresh-like quality and contains only natural ingredients. There are two main reasons to adapt minimal processing of foods; first, supply of safe and fresher products with least possible losses in nutrients and secondly delivery of high quality products to the consumers (Ahvenainen 1996). These techniques are used either alone or in combination of two or more to achieve the product with desired attributes. Such approaches could be categorized in various thermal and non-thermal techniques, application of biopreservation or natural antimicrobials as well as applications of hurdle concept (Fig. 10.1).

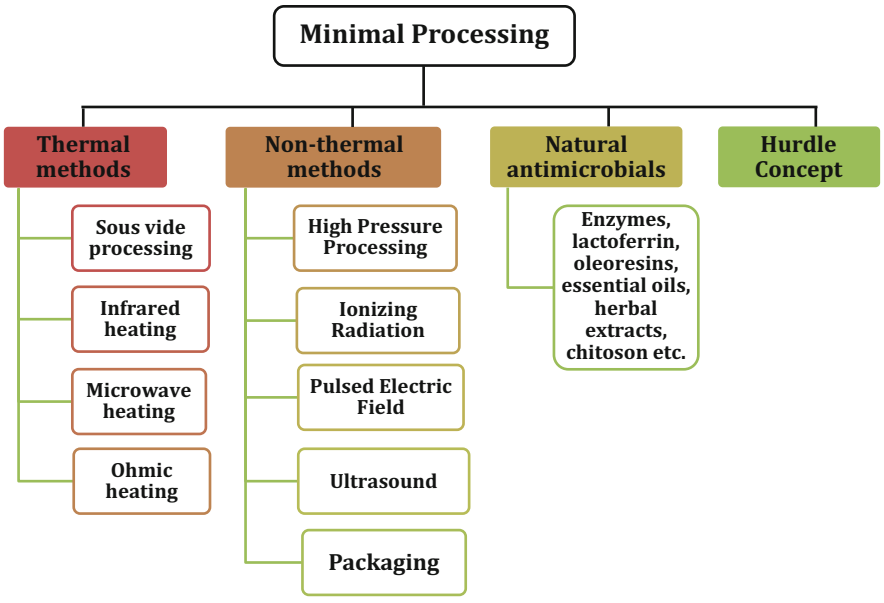

Fig. 10.1 Approaches for minimal processing technologies of meat and fish products

10.2.1 Minimal Processing with Thermal Methods

10.2.1.1 *Sous-vide* Processing

The surge in consumer demands for minimally processed refrigerated convenience foods with extended shelf life and fresh like products has led to a growth of *sous-vide* processing technology. *Sous-vide* means "under vacuum" in French, and the term describes both the process and end product. This technique was originally developed for the catering industry. This method allows the manipulation of prepared food after thermal treatment without the risk of microbial contamination (Armstrong 2000). It is an advanced method of cooking whereby fresh food is vacuum sealed in heat-stable, high barrier plastic pouches or films, and then cooked (pasteurized) to a time-temperature combinations, which is sufficient to destroy vegetative pathogens as well as maximizing the sensory characteristics of the product (Juneja et al. 2006). Rapid chilling to avoid germination and outgrowth of surviving bacterial spores, stored refrigerated, and reheated before consumption, follows this. According to James and James (2005), there are several recommendations for the *sous-vide* processing, which involves (Table 10.1):

1. Pre-packaging, in specialized plastic bags or pouches, of prepared raw or par-cooked foods,
2. Sealing of prepared foods in bags (or pouches) under vacuum to remove the air surrounding the food,
3. Cooking of vacuum-sealed food for immediate consumption or to controlled pasteurization temperatures,
4. Rapid chilling of pasteurized food product,
5. Storage under controlled conditions until required, and
6. Reheating (regenerating) the food product before serving.

Table 10.1 Recommendations for *sous-vide* processing in United Kingdom

Stage in process	Requirements
Initial cooking	Minimum +70 °C, time not specified
Portioning	<10 °C within 30 min
Chilling time	1.5 h to +3 °C
Storage temperature	−18 °C
Shelf-life at storage temperature	In general up to 8 weeks without significant changes
Critical temperature during storage	+5 to +10 °C; Consumption within 12 h
	Above +10 °C destroy
Distribution	For short periods insulated containers is sufficient
	For longer periods, refrigerated transport is required
Re-heating temperature	Minimum +70 °C

James and James (2005)

Advantages associated with *sous-vide* processing include superior flavour profile, increased tenderness; retained colour and nutrients, reduced oxidative changes and enhanced shelf life (Church and Parsons 2000; Vaudagna et al. 2002). In meat products the most important disadvantage associated with this technology is to retain the juices inside the package during thermal treatment (Szerman et al. 2007). This problem is relevant, especially regarding commercial profits and product appearance. Hence, the use of mild thermal treatments (Vaudagna et al. 2002) and the addition of brine containing sodium chloride (NaCl) and alkaline phosphates are commonly used to reduce cooking loss. There are also some concerns regarding the risks posed by anaerobic pathogens, particularly *Clostridium botulinum*. In order to directly address this risk, it is recommended by the *Sous vide* Advisory Committee that *sous-vide* products should undergo a pasteurization specifically designed to produce a 6D reduction in the numbers of spores of the most heat resistant type of *C. botulinum*, followed by storage at a temperature to prevent germination of any spores. It has been claimed however that the required heat treatment caused unacceptable damage to sensory quality. Therefore, less severe heat treatments have been proposed with application of additional hurdles (preservatives, salt, spices, bacteriocins). Application of *sous-vide* processing in various meat and fish products have been reported by various researchers (Table 10.2). These findings suggest that the *sous-vide* processing keeps spoilage microorganisms at low level and are effective in protecting the product from microbial, physical, and sensory quality degradation.

10.2.1.2 Infrared Heating

Infrared (IR) radiation is the part of the electromagnetic spectrum lying between ultraviolet (UV) and microwave (MW) energy. It can be, near-infrared (NIR), mid-infrared (MIR), and far-infrared (FIR), corresponding to the spectral ranges of 0.75–1.4, 1.4–3, and 3–1,000 μm, respectively. Infrared is a unique heating source and its thermal energy is primarily absorbed on solid food surfaces and has very limited penetration capability. Exposing an object to an infrared heating source causes its surface to increase temperature followed by consequent transfer of heat to the centre of the solid food by conduction. Most of the solid foods are generally low in thermal conductivity thus heat transfer to the interior is very slow when compared with highly conductive materials (Huang 2004). In order to achieve optimum energy and efficient practical applicability of IR heating in the food processing industry, combination of IR heating with microwave and other common conductive and convective modes of heating holds great potential.

Infrared radiation does not have any direct necessity to heat the air for keeping oven temperatures with reduced humidity. These can result energy saving and conservation of cooking loss (Sheridan and Shilton 1999). These are the features which made IR heating as an important means of thawing, cooking, drying, roasting, baking, blanching, and pasteurization of food and agricultural products (Lloyd et al. 2003; Ranjan et al. 2002; Staack et al. 2008). In the IR region, the absorption coefficients of ice and water are approximately same (Sakai and Mao 2006), and this prevents runaway heating/overheating, making IR heating a possible thawing method.

Table 10.2 Effects of *sous-vide* (SV) processing on different properties of meat and fish products

Products	Processing conditions	Effects	References
Beef	Whey protein concentrate (WPC), sodium chloride (NaCl), modified whey protein concentrate (MWPC), sodium tripolyphosphate (STPP)	Muscles with STPP + NaCl presented a significantly higher total yield in comparison to others and lower shear force value than control. Cooking with STPP + NaCl or WPC/MWPC + NaCl depicted compact and uniform microstructures. Muscles with STPP + NaCl showed a pink colour, other treatment muscles presented colours between pinkish-grey and grey-brown. STPP + NaCl added samples presented the highest values of tenderness and juiciness. Addition of STPP + NaCl had a better performance than WPC/MWPC + NaCl.	Szerman et al. (2012)
Pork cheeks	Vacuum packaging, cooking at different time-temperature combinations	Low weight loss and high moisture in samples cooked for a shorter time and at a lower temperature. Samples cooked at 60 °C showed more lightness (L*) and redness (a*). Higher TBARS number for samples cooked for 12 h at 60 °C and lower for those cooked for 12 h at 80 °C. Samples cooked at 80 °C for 12 h showed lower values for most textural parameters.	Sánchez del Pulgar et al. (2012)
Pork loin	Vacuum packaging, cooking (70 °C/12 h) and storage (0, 5 and 10 weeks at 2 °C)	Sensory spoilage preceded microbiological spoilage. SV processing ensured the absence or very low counts of microbial cause of spoilage and *Enterobacteriaceae* even after 10 weeks of storage at 2 °C. Pork loin was unacceptable after 10 weeks mainly due to deterioration of meaty flavour and odour.	Diaz et al. (2008)
Beef (*Semitendinosus* muscles)	Sodium chloride (0–1.4 %), sodium tripolyphosphate (0–0.5 %)	Both salts alone or in combination successfully reduced cooking loss. The best results were obtained for the combinations 0.25 % STPP + 1.20 % NaCl and 0.25 % STPP + 0.70 % NaCl, and temperatures between 60 and 65 °C, where cooking loss was reduced close to 0 %. Temperature increment and NaCl addition produced a redness reduction, which was partially countered by STPP.	Vaudagna et al. (2008)

(continued)

Table 10.2 (continued)

Products	Processing conditions	Effects	References
Beef	Pre-injection tumbling, brine (WPC and NaCl) addition and post injection tumbling, vacuum packaging, cooking	Addition of brine decreased markedly the total weight loss and shear force of cooked beef muscles. Pre-injection tumbling did not affect most of the evaluated parameters. Extended post-injection tumbling improved shear force values and colour uniformity and diminished the size of the pores in brine added muscles.	Szerman et al. (2007)
Korean seasoned beef	Boiling, simmering and slicing, evaporative concentrated brine, soy sauce, packaging in gas-barrier film pouch, pasteurization	The *sous-vide* packaging was effective in protecting the product from microbial, physical, and sensory quality degradation. Based on the sensory quality, the shelf life of SV processed products was around 12 days when stored at 3 and 10 °C, whereas for the conventionally processed products, it was 7 and 3 days, respectively.	Jang and Lee (2005)
Salmon	Processing at various time–temperature combinations, storage at 2 or 10 °C	*Staphylococcus aureus*, *Bacillus cereus*, *Clostridium perfringens* and *Listeria monocytogenes* were not found in any of the samples. The heat treatment of 90 °C for 15 min was most effective for extending the shelf life of fish (>45 days). Sensory characteristics were sub-optimal.	Gonzalez-Fandos et al. (2005)
Fresh salmon and trout	Vacuum packaging, pasteurization (90 °C for 10 min), storage (for 3, 20 and 45 days at 4 °C)	Trout cooked by the *sous-vide* method and stored for 20 and 45 days maintained the lipid content of the raw species in comparison to the traditional method. Traditional and *sous-vide* cooking maintained and even increased the protein and lipid content as well as the fatty acid characteristics of salmon.	García-Linares et al. (2004)
Rainbow trout	Vacuum packaging into a polyethylene-polyamide pouch, processing at different time-temperature combinations, storage (2 °C and 10 °C)	The batches stored at 2 °C had lower growth counts of mesophiles and psychrotrophs and counts decreased by increasing the heating temperature and time. *S. aureus*, *B. cereus*, *C. perfringens* and *L. monocytogenes* were absent in all samples. Neither aerobic nor anaerobic spores were detected in the trout samples processed at 90 °C for 15 min and stored at 2 °C after 45 days. A heat treatment of 90 °C for 15 min was most effective to extend the shelf life.	Gonzalez-Fandos et al. (2004)

(continued)

Table 10.2 (continued)

Products	Processing conditions	Effects	References
Chicken wings	Vacuum-packaging, cooking (75 and 90 °C), storage (2 and 7 °C)	*Sous-vide* treatment was an effective method to prevent lipid oxidation during storage and enhanced shelf life of chicken wing products. Chicken wings had lower TBARS numbers, aerobic and anaerobic plate counts throughout the 7 week of storage when compared with the control but had no effect on the Warnar-Bratzler shear force of chicken wings. At 2 °C cooked chicken wings had a shelf life of at least 7 week.	Wang et al. (2004)

Application in raw products: According to Sakai and Mao (2006) thawing of tuna using FIR heating avoided drip losses and discolouration, which led to develop commercial thawing equipment and a refrigerator with a partial defrosting system using IR energy. Evolution of surface temperature due to absorption of IR energy is a significant parameter to control thawing using IR energy.

Application in ready-to-eat products: Conventional cooking ovens, that use high velocity hot air, can cause surface deterioration, overheating, oxidation, charring, impingement damage, low yields and high energy costs. Thus infrared cooking has drawn the attention of food and processed meats sector to overcome these problems. Braeckman et al. (2009) observed the influence of combined IR-grilling/hot air cooking conditions on the selected quality and sensory attributes of hamburgers. It was found that longer the grilling stage, the higher the temperature of hamburger at the point where it exits the grill and enters the convection oven, thus effectively reducing the cooking time. Longer grilling stage resulted in more development of crust prior to convection cooking, thus potentially preventing moisture and fat loss during the subsequent convection cooking. Compared to only grilling of the hamburgers, the effect of single-sided grilling time on the moisture, total weight and fat loss is reduced when grilling is followed by convection cooking.

Infrared heating also has the potential of surface pasteurization and can become a common industrial practice for production of safe and wholesome foods. It inactivates the pathogenic microorganisms by damaging their intracellular components, such as DNA, RNA, ribosomes, cell envelope, and/or cell proteins (Krishnamurthy et al. 2008a). Infrared heating was used for pasteurization of frankfurters to kill *L. monocytogenes* contaminated on its surface immediately prior to final packaging and to reduce the risk of foodborne listeriosis caused by these products (Huang 2004). Huang and Sites (2008) developed an infrared pasteurization process with automatic temperature control for inactivation of surface contaminated *L. monocytogenes* on ready-to-eat meats such as hotdogs. The temperature of the product surfaces was effectively controlled during the IR pasteurization process;

overcooking and burning of the hotdogs was prevented. Use of IR heating for pasteurization of oysters, Japanese noodles, and secondary pasteurization of boiled fish paste was reported by Sakai and Mao (2006). Sheridan and Shilton (1999) evaluated the efficacy of cooking hamburger patties by infrared sources at λ_{max} of 2.7 μm (Mid-IR) and at λ_{max} of 4.0 μm (Far-IR). The far infrared radiation source helped to achieve target core temperature at a lower surface temperature, with less surface drying and charring. The gas consumption when using the longer wavelength infrared source was reduced by 55 % over that for the shorter wavelength, higher energy source. Application of infrared heating for the processing of meat and fishes is not fully explored and it is expected that the utilization of IR heating in the food processing sector, especially in the area of minimal processing of food and meat products will be fully tapped in the near future.

10.2.1.3 Microwave Heating

It refers to the use of electromagnetic waves of certain frequencies to generate heat in material. Most commonly used microwave frequencies for food applications are 2,450 MHz and 915 MHz. Ionic conduction and dipolar rotations are two major mechanisms of interaction of foods with microwaves. In ionic conduction, the positively charged ions accelerate in the direction of the electric field in microwave oven, while negatively charged ions move in the opposite direction (Sahin and Sumnu 2006). Since electric field changes its direction depending on frequency, so the direction of the motion of the positive and negative ions. Moving particles collide with the adjacent particles and set them into more agitated motion, thus temperature of the particle increases. In the presence of polar molecules, heat generation in microwave oven takes place by the mechanism of dipolar rotation. When polar molecules interact with electric field, they try to orient themselves in the direction of the field and they collide with the other molecules. The change in the direction of the field results in further collision since they try to line up with the reversed directions, thus thermal agitation and heating take place (Sahin and Sumnu 2012). Microwave heating technique has been used in the thawing, heating, cooking, drying and frying of foods.

Application in raw products: Microwave thawing and/or re-heating has significant advantages over the conventional methods. These include shortening of the thawing time from hours to minutes, reduction in the plant space devoted to thawing and the elimination of the requirement for thawing chambers, an increase in the hygienic conditions and a decrease in the microbial load of the thawed products. Quality changes of anchovy and bluefish thawed by refrigerator, microwave, and running water were compared by Baygar et al. (2004). Microwave thawing prolonged the spoilage of fish. The spoilage of samples thawed in water and a refrigerator took place after the third thawing process while microwave-thawed samples were spoiled after the fourth thawing process. In another study, the effect of different thawing methods such as microwave and refrigerator thawing on quality of shrimp was

evaluated (Boonsumrej et al. 2007). It was found that microwave thawing resulted in higher thawing loss than thawing in refrigerator, however thawing method did not affect the texture of shrimps significantly. Mahmoud et al. (2009) studied the oxidative changes of lipids during microwave heating of minced fish flesh. During microwave heating of fresh minced fish flesh, lipids contained in them were relatively stable with respect to oxidation. Small changes in monounsaturated fatty acids and polyunsaturated fatty acids took place in minced flesh after 24 min of microwave heating.

Application in ready-to-eat products: Microwave cooking/frying of ready-to-eat meat and fish products reduces the requirement for temperature and time of treatment due to decrease in the temperature gradient. Consequently, a reduction in the cooking losses is achieved besides the retention of initial characteristics of the product. The effects of different reheating methods on the quality characteristics of precooked ground pork patties with different combinations of salt (1.2 %) and phosphate (0.03 %) were studied by Choi et al. (2008). The reheating rate by microwave oven was found faster than by electric grill, and decreased with increase in salt and addition of phosphate. Cooking loss and reduction in patty diameter after reheating by microwave oven were higher than by electric grill, and these values decreased with increasing salt/phosphate levels. The hardness of patties reheated by electric grill was lower than patties reheated by microwave oven, and the addition of phosphate increased the hardness with both reheating methods. Microwave reheating of ready-to-eat surimi-based shrimp-imitation product produced undesired textural changes (Uzzan et al. 2006). A significant increase in the toughness was observed during microwave heating only if water starts boiling. Boiling under microwave was accompanied by a considerable product shrinkage, which can increase the density of the products.

In a study on the effect of microwave cooking on the microstructure and quality of meat in goat and lamb, Yarmand and Homayouni (2009) observed fat cell distribution in the structure of cooked *semimembranosus* muscle (SM). They used conventional, domestic (2,450 Hz, 700 W) and industrial microwave (2,450 Hz, 12,000 W) cooking until an internal temperature 70 °C was achieved. The amount of fat in raw lamb and goat SM muscle was reduced after heating. In microwave heating, the fat reduction in goat SM muscle was greater than conventional heating. The cooking loss was greater in goat SM than lamb. The overall migration of fat globules during microwave cooking was found higher than conventional cooking. Microstructural and mechanical properties of camel *longissimus dorsi* muscle during microwave heating along with roasting and braising was studied by Yarmand et al. (2013). Shear value and compression force were increased during microwave heating more than roasting and braising. Results showed that roasting caused more structural damage by either braising or microwave heating.

Microwave processing technology is also finding its application in the pasteurization and sterilization of foods. Pasteurization of mechanically tenderized beef inoculated with *E. coli* O157:H7 has been studied using temperature controlled two-stage microwave heating (Huang and Sites 2010). *E. coli* and background microflora

were completely inactivated by heating at temperatures above 70 °C for more than 1 min. According to Huang (2005), it is possible to reduce *L. monocytogenes* by 7-log in inoculated beef frankfurters using 600 W microwave oven for 12–15 min. Huang and Sites (2007) demonstrated the feasibility of a proportional integral differential controlled microwave heating process in the case of in-package pasteurized frankfurters. Overall rate of inactivation of *L. monocytogenes* was 30–75 % higher with microwave in-package pasteurization as compared to water immersion heating at the same surface temperatures. Above findings suggest that microwave thawing of meat delays the meat spoilage while enhances thawing loss. Microwave used for cooking of meat and meat products reduces the temperature and time required for cooking thus makes it faster with either increased or decreased cooking loss and acceptable toughness as well as tenderness. In the case of pasteurization, microwave decreases the pathogenic microbial counts. Microwave cooking is also associated with the non-uniform heating of foods, lack of colour and flavour development. Thus, combination of microwave with other heating methods can be used to overcome these drawbacks.

10.2.1.4 Ohmic Heating

In recent decades, technologies that utilize the passage of electrical current directly through food products are receiving attraction by the food industry. Some of these like ohmic cooking technologies are now being used on a commercial scale for processing a broad range of meat and other food products. Ohmic heating has been developed two decades ago and now is in commercial scale operations for processing a several food products, especially those containing particulates. Ohmic heating (OH), also referred to Joule heating, electro-heating, and electro-conductive heating and it is defined as a process wherein electric current is passed through materials (Vicente et al. 2006). The heat is generated in the form of internal energy transformation from electric to thermal within the material (Sastry and Barach 2000). In ohmic heating processes, foods are made part of an electric circuit through which alternating current flows, where heat is generated within the foods due to the electrical resistance. Therefore, in a liquid–particulate food mixture, if the electrical conductivity of the two phases is comparable, heat is generated at the same or comparable rate in both phases. Heat can be generated faster in the particulate than in the liquid foods. Ohmic methods thus offer a way of processing food at the rate of high temperature short time (HTST) processes without the limitation of conventional HTST on the limited heat transfer to particulates.

Improved product quality and reduced processing times are the main advantages of ohmic heating over other conventional processes (McKenna et al. 2006). Ohmic processing enables to heat materials at extremely rapid rates (Sastry 2004) with substantial reduction in processing time resulting in higher product quality (i.e. product integrity, flavour and nutrients retention) (Shirsat et al. 2004a; Castro et al. 2003; Tucker 2004; Vicente et al. 2006). Ohmic treatment has found a wide range of applications such as preheating, cooking, blanching, pasteurization, sterilization, and extraction of food products (Icier et al. 2005; Leizerson and Shimoni 2005a, b).

Application in raw products: Frozen meat samples were thawed by ohmic technology in a liquid contact thawing methods (Wang et al. 2002). Thawing process was found uniform and quicker with retained quality of meat, such as colour and pH. These results demonstrated the potential uses of OH in contact thawing, especially for meat products. The changes in the histology and the texture of beef cuts during ohmic thawing were compared with those during conventional thawing method by Icier et al. (2010). Ohmically thawed beef cuts samples were harder than conventionally thawed ones while the conventional thawing caused springier beef cuts. These workers pointed the voltage gradient (10, 20 and 30 V/cm) applied during ohmic as an important parameter for textural properties of beef cuts in terms of the hardness, springiness, gumminess and chewiness.

Application in ready-to-eat products: Sarang et al. (2007) developed a blanching method to increase the ionic content in chicken chow mein and compared the OH (60 Hz up to 140 °C) uniformity of blanched particulate against untreated samples. It was observed that following pre-treatment, it may be possible to uniformly heat the entire product during OH and that such pre-treatment does not compromise with product quality. Ohmic heating was found to produce quality levels comparable to those achieved by conventional methods with reduced cooking losses in beef *biceps femoris* muscle tumbled with 3 % salt solution for 16 h (Zell et al. 2009). Intact turkey meat was cooked using low temperature long time (LTLT) and high temperature short time (HTST) protocols in a combined ohmic/convection system and they were compared to conventional steam cooking (Zell et al. 2010a). Rapid ohmic heating resulted in levels of quality which are broadly comparable to those achieved by conventional cooking with an 8–15-fold reduction in cooking time showing its potential to cook whole turkey breast meat. Ohmic heating treatments of beef *semitendinosus* muscle eliminated *L. innocua* below the detectable level, thus demonstrating the safety of these protocols (Zell et al. 2010b). It was also found that whole beef cooked rapidly by ohmic heating (sevenfold time reduction with the LTLT protocol) and gave quality levels comparable to those achieved by conventional methods while it also reduced cooking losses. Further, the most rapid ohmic cooking protocol (HTST) gave similar instrumental quality values to conventional cooking, despite a 15-fold reduction in cooking time.

Piette et al. (2004) observed no loss in the quality of cooked basic bologna emulsion in terms of appearance and texture when ohmic cooking (64–103 V; 3.9 °C/min to 10.3 °C/min; to 70–80 °C) was substituted by traditional smokehouse cooking (180 min cycle; to 70 °C). Bozkurt and Icier (2010) reported that ohmic heating (20, 30 and 40 V/cm) of ground beef sample was faster than the conventional cooking. Ohmically cooked samples were firmer than those by conventionally cooked but no differences were found in yield and fat retention. The colour was more homogeneous within the ground beef cooked ohmically. Thus in muscle foods, ohmic heating is being used in thawing, blanching and cooking process and it showed several advantages when compared to conventional technologies. It results in higher or similar cooking yield and sensorial quality retention as compared to conventional cooking methods. Additionally more uniform lighter and browner colour could be

developed in ohmically cooked meat products. Ohmic cooking effectively inhibits microbial growth by providing uniform temperature distribution in the product and cooks the product extremely fast.

10.2.2 Minimal Processing with Non-thermal Methods

10.2.2.1 High Pressure Processing

Among the novel non-thermal food processing methods, the application of high pressure (HP) has been the most successful so far. High-pressure processing (HPP) treats product statically at or above 100 MPa by means of a liquid transmitter. According to Patterson (2005), it is common to use pressure from 500 to 900 MPa. High-pressure processing has various advantages over other non-thermal technologies. Food can be processed at ambient or even at lower temperatures. It is the isostatic transmission of pressure; the processed material experiences the pressure instantaneously with no gradient, resulting in uniform treatment irrespective of the size and geometry of the material. High-pressure modifies only non-covalent bonds like hydrogen, ionic and hydrophobic bonds and does not affect small molecules such as flavour compounds and vitamins. Therefore, high-pressure processing leads to less degradation in the overall quality of processed foods as compared to heat treated foods. In addition, high pressure processing takes lower time and energy (Simonin et al. 2012).

Application in raw products: In raw meat so far HPP has been used for increasing tenderness with improved functionality and food safety. The pressurisation influences the physicochemical and functional properties of meat and muscle proteins such as gelation and water binding capacity (Jiménez Colmenero 2002; Sun and Holley 2010) in addition to the destruction of spoilage and pathogenic microorganisms. High pressure processing also causes an immediate drop in pH of pre-rigor muscle as a result of accelerated glycolysis. Application of more than 200 MPa to fresh meat results in myofibrillar protein denaturation, but stromal proteins such as collagen remains stable. Tenderness values are generally higher in pre-rigor meat subjected to HPP processing as compared to controls. Myofibrillar protein solubility of post-rigor muscle is increased when subjected to HPP (Souza et al. 2011). HPP can change the molecular composition of meat, enhance the stability of meat gels and modify the textural properties of biopolymers such as proteins and polysaccharides yielding gel-type products. This allows lower salt levels to be used and achieves high water binding capacity with improved texture in processed meat products (Chen et al. 2006; Chattong et al. 2007; Sikes et al. 2009). In seafood pastes, which generally show low gel-setting abilities, HPP resulted smoother gels with finer texture (i.e. more elastic than those produced by heat alone) (Hwang et al. 2007). These effects could be resulted from greater ionic, hydrogen bonding and hydrophobic interactions. Moreover, the pressure is thought to protect proteins against subsequent heat-induced denaturation (Uresti et al. 2005). Several workers have attempted HPP in raw meat and fish and observed its beneficial effects on selected quality parameters (Table 10.3).

Table 10.3 Effects of HPP on different properties of raw meat and fish products

Products	Processing conditions	Effects	References
Raw and cooked ground beef	0.1, 300, or 600 MPa, phosvitin	Phosvitin and HHP treatment at 300 MPa synergistically reduced microbial growth. HHP treatment at 600 MPa reduced microbial counts to undetectable levels.	Jung et al. (2013)
Chicken breast meat	300, 600 and 800 MPa	Treatment at 300 MPa did not induce significant lipid oxidation during storage period, while 600 and 800 MPa enhanced formation of secondary lipid oxidation products.	Alves et al. (2012)
Chicken breast fillet	300 MPa (5 min, 20 °C), liquid antimicrobial edible coating, MAP packaging	Synergistic action of high pressure processing with antimicrobial coating in MAP extended the durability of chicken breast fillets, which maintained their sensory and microbiological qualities for up to 28 days.	Rodríguez-Calleja et al. (2012)
Turkey meat (PSE like)	50, 100, 150 and 200 MPa (5 min at 4 °C)	Pressures of 50 and 100 MPa increased the water holding capacity of low pH meat. 50 and 100 MPa pressure led to formation of a better gel network. Application of high pressure significantly increased total protein solubility in both low and normal pH meats. Aggregation of myofibrillar proteins increased in low pH meat at higher pressure (200 MPa).	Chan et al. (2011)
Chicken breast fillet	300, 450 and 600 MPa (5 min, 15 °C)	Pressures of 450 and 600 MPa almost completely eliminated *Salmonella*, *Escherichia* and *Listeria.* The 300 MPa pressure significantly reduced flavour, aroma strength and juiciness, and 450 MPa produced breast fillets with the weakest aroma. Increasing pressure increased cooking loss and colour by increasing lightness (L*), redness (a*) and yellowness (b*) values and pressure of 450 MPa and higher induced lipid oxidation.	Kruk et al. (2011)
Pork (pre-rigor)	215 MPa (15 sec, 33 °C)	HPP partially inhibited post-mortem metabolism, indicated by lower muscle lactate levels and higher ultimate pH values. Cook and drip loss were both reduced in HPP treated muscles. HPP treated sides were tender.	Souza et al. (2011)

(continued)

Table 10.3 (continued)

Products	Processing conditions	Effects	References
Chilled coho salmon	HHP of 135 MPa, 170 MPa and 200 MPa (30 sec)	Marked inhibitory effect on aerobe, psychrotroph, *Shewanella* spp. and *Pseudomonas* spp. counts and it increased with the pressure levels. Higher peroxide value in untreated and sample with 135 MPa pressure. TBARS number was increased in 170 and 200 MPa pressurized samples.	Aubourg et al. (2010)
Chicken breast and beef muscle	400 and 600 MPa (15 min, 5 °C)	Lipid oxidation in the pressurised and oxygen-exposed chicken and beef meat remained stable during 24 h of cold storage. Pressure treatment of beef and chicken did not induce severe changes of their raw aroma profiles.	Schindler et al. (2010)
Duck muscle gel	0-500 MPa (10-40 min)	Treatment at >300 MPa resulted in the decrease of cooking loss, 'a' and 'b' values, and increase of 'L' value, hardness, springiness, cohesiveness and chewiness	Chen et al. (2010)
Turkey breast muscle	0.1–300 MPa, (0.1 sec and 1, 2, 3, 5, 10 and 15 min at 25 °C)	At 150 MPa diffusion coefficient of NaCl infusing into the meat was the maximum whereas diffusion coefficient of moisture infusing out of the sample was found to be a minimum. Treatment at 150 MPa resulted in turkey breast with minimum hardness, gumminess and chewiness.	Villacís, et al. (2008)
Beef and chicken muscle	0.1–800 MPa	Pressure treatment of beef samples at room temperature led to increases in TBARS number after 7 days storage at 4 °C and this increase was more marked after treatment at pressures ≥400 MPa than after treatment at lower pressures. Similar results were found in those samples treated at 40 °C, but at 60 °C and 70 °C, pressure had little additional effect on the oxidative stability of the muscle. Pressure treatments of 600 MPa and 800 MPa, at all temperatures, induced increased rates of lipid oxidation in chicken muscle, but, in general, chicken muscle was more stable than beef to pressure.	Ma et al. (2007)

(continued)

Table 10.3 (continued)

Products	Processing conditions	Effects	References
Minced albacore tuna muscle	275 and 310 MPa (2, 4, and 6 min)	High hydrostatic pressure improved shelf life for >22 days at 4 °C and for >93 days at frozen storage (−20 °C). High pressure denatured muscle proteins forming gels with increasing hardness as pressure and holding time increased and also promoted lipid oxidation and colour improvement.	Ramirez-Suarez and Morrissey (2006)
Raw carp fillets	100, 140, 180 and 200 MPa (15 and 20 min at 4 °C), vacuum packaging	TBARS number and free fatty acid value increased with pressure and pressurization time. The CIE colour values, i.e., L*, a* and b* of fillets also increased with pressure and pressurization time.	Sequeira-Munoz et al. (2006)
Sea bass fillets	Upto 500 MPa (5 min)	Increase in lightness, slight change of hue, decrease of exudation and water holding capacity of pressurized sample. Pressure treatment above 300 MPa increased fish hardness after storage than untreated sample. Pressure of 500 MPa after 7 days of storage, allowed a total aerobic count equivalent to that of untreated fresh fish fillet.	Chéret et al. (2005)
Fresh oysters	100–800 MPa (10 min, 20 °C)	HP treated oysters had higher pH and lightness, which increased with pressure. HP induced changes in colour imparted a cooked, more voluminous and juicy appearance to the raw oyster tissue. Denaturation of oyster muscle proteins occurred due to HP treatment. Moisture content increased while ash and protein contents decreased with increasing treatment pressure up to 800 MPa.	Cruz-Romero et al. (2004)
Beef	50–600 MPa (20–300 sec, 10 °C)	Pressure higher than 300 MPa induces modifications in meat colour parameters, a decrease in the total flora and a 1 week delay before microbial growth (520 MPa, 260 sec). Redness of the 520 MPa treated samples decreases gradually, in relation to the increase of metmyoglobin.	Jung et al. (2003)

(continued)

Table 10.3 (continued)

Products	Processing conditions	Effects	References
Fish (Redfish, Salmon, Whiting, Rainbow trout, Cod, Haddock)	200 MPa	Organoleptic characteristics of the high pressure treated fillets were better compared to the conventional water thawed samples. Thaw drip is markedly reduced, lightness and hardness are increased and microbial status of fillets is greatly improved during high pressure thawing.	Schubring et al. (2003).
Turbot fillets	100, 140, 180, 200 MPa (15 and 30 min, 4 °C)	High pressure treatment had no effect on free fatty acid content but influenced the lipid oxidation. The change in colour was gradual with both increase in pressure level and holding time. Myosin showed a full denaturation at 200 MPa.	Chevalier et al. (2001)
Fresh Atlantic salmon	0, 100, 150, 200 MPa (0, 10, 30 and 60 min), MAP	A shelf life extension of 2 days was obtained with 150 MPa for 10 min at 5 °C. HP treatment with MAP extended the threshold value for microbial spoilage of salmon for at least 18 days at 5 °C. Spoilage microorganisms were more susceptible to HP in the presence of MAP. Combined HP and MA treatments promoted a detrimental effect on colour and changes in the balance of oxidative rancidity.	Amanatidou et al. (2000)
Pollack, mackerel, tuna, cod, salmon trout, carp, plaice, anglerfish, octopus	150–800 MPa	High pressure (>150–200 MPa) treatments for 5 min resulted in a cooked appearance; octopus retained a raw appearance until 400–800 MPa. Hardness of cod increased because of high pressure processing at 200 and 400 MPa during frozen storage of 6 months.	Matsera et al. (2000)
Frozen ground beef	140, 210, 280 and 350 MPa (5, 15, and 30 min)	The lowest temperature at which the beef was efficiently thawed was –24 ± 2 °C. HHP treated beef thawed much faster than controls. HHP thawing resulted in similar colour and texture to controls.	Zhao et al. (1998)

Application in ready-to-eat products: High hydrostatic pressure has been forecasted to be convenient for high quality with chemical free preserved meat products. This process provides fresh products with natural flavours and tastes as it is demanded by consumers. HP processing results in an effective reduction of microbial counts by keeping foods with minimal effects on nutritional and sensory characteristics. Thus, HP processing becomes very useful as a post-packaged preservation technology for ready-to-eat (RTE) whole or sliced meat products and seafoods. Antimicrobial attribute of high pressure processing supposed to be due to combination of breakdown of non-covalent bonds and the puncturing or permeabilisation of the cell membrane. Vegetative cells are inactivated at about 3,000 bars at ambient temperature, while spore inactivation requires much higher pressures (6,000 bars or more) in combination with a temperature rise to 60–70 °C. Gram negative bacteria are generally more sensitive to pressure than Gram positive bacteria (Patterson 2005). The inactivation of spoilage and pathogen microorganisms by HPP has been studied in several meat products, and depending on the type of product, different effects of pressure, temperature, and holding time have been determined (Aymerich et al. 2005, 2008; Chung et al. 2005; Garriga et al. 2004; Tanzi et al. 2004).

High pressure processing has been applied as a preservation method to a wide range of meat products such as cured meats, processed meats or meats for further processing, and ready meals. Some high hydrostatic pressure (HHP) treated meat products are already sold in the marketplace: sliced ham and turkey, pork and poultry cuts, thick sliced ham, chicken and turkey products, whole and sliced Serrano ham, salami, and chorizo are available in Spain; natural, minimally processed cooked sliced meat, roasted chicken (whole birds, breasts, and drumsticks), sliced chicken and turkey, chicken sausages, sliced turkey and strips of chicken in modified atmosphere packaging (MAP) and prosciutto (whole and sliced) are sold in the United States. Nitrate-free HHP treated cooked pork products are sold in Japan; HHP treated Parma ham (prosciutto), salami, and pancettas are sold in Italy (PFV 2009). Applications of high pressure processing in various ready-to-eat meat and fish products as well as their effects have been summarized in Table 10.4.

It is clear from the discussed results that HP processing has the widest application in the meat industry as compared to other minimal processing approaches. When used at appropriate pressure level and suitable processing conditions, HPP improves several physicochemical, functional, and sensory characteristics of the processed meats besides reduction of pathogenic and spoilage microbial counts. HPP also affects colour and lipid peroxidation in meat and fish products when pressure level is not appropriate.

10.2.2.2 Ionizing Radiation

Radiation which has sufficient energy to move the atoms of another molecule, but are insufficient to change it chemically termed as “non-ionizing radiation”, against the “ionizing radiation” that has enough energy to break chemical bonds. As far as application in foods is concerned three types of ionizing radiations are being used

Table 10.4 Effects of HPP on different properties of ready-to-eat meat and fish products

Products	Processing conditions	Effects	References
Pork sausages with carrot fibre	500 and 600 MPa (1 s, 3, 6 and 9 min, at 40, 50 and 60 °C)	HPP and carrot dietary fibre improved emulsion strength and firmness of sausages. An increase in L* value and decrease in a* value were observed. HP treatment synergistically cooperates with carrot dietary fibre improving homogeneity, creaminess, fattiness, and firmness.	Grossi et al. (2011)
Pork sausage with carrot fibre and corn starch	400, 600 and 800 MPa	Degree of redness was mainly affected by pressure level and heat treatment.	Grossi et al. (2012)
Cooked chicken	600 MPa (2 min, 20 °C), sodium lactate, pressure-resistant *Weissella viridescens* strain	HPP treatment alone gave a <3.3 log reduction of *L. monocytogenes* in cooked chicken. 2 % Na lactate with HPP kept *Listeria* numbers below 50 CFU g^{-1} throughout storage.	Patterson et al. (2011)
Beef sausage batter	400 MPa (2 min at 10 °C)	HPP produced significant improvement in the moisture retention of the cooked products. The hardness and gumminess of pressure-treated samples was higher compared to untreated samples. There was a slight increase in "whiteness" with pressure treatment. A greater acceptability in both appearance and texture was noted of pressure treated sausages of lower salt content compared with non-pressure-treated samples.	Sikes et al. (2009)
Cooked ham	400 MPa (10 min at 17 °C), antimicrobial alginate films	HPP resulted in the reduction of 3, 4 log units of *L. monocytogenes*. Combination of antimicrobial packaging and HPP extended storage life up to 60 days.	Marcos et al. (2008a).

(continued)

Table 10.4 (continued)

Products	Processing conditions	Effects	References
Frankfurters	(400 MPa/10 min/30 °C), thermal superficial pasteurization, vacuum packaging	Both superficial pasteurization and pressurization caused decrease in the levels of total viable and lactic acid bacteria counts.	Ruiz-Capillas et al. (2007a)
"*Chorizo*" (Spanish dry-cured sausage)	350 MPa (15 min)	HP treatment reduced the level of lactic acid bacteria by <1 log unit and production of biogenic amines.	Ruiz-Capillas et al. (2007b)
Low-acid fermented sausages (*fuet* and *chorizo*)	300 MPa (10 min, 17 °C), three-strain cocktail of *Salmonella* and *L. monocytogenes*	Application of HPP as an additional hurdle to the ripening process produced a greater decrease in the *Salmonella* population, showing lower counts (3 MPN/g) in ripened sausages. A discolouration of sausages was observed, coinciding with an increase in L* values of raw sausages pressurized at 300 MPa.	Marcos et al. (2005)
Cooked meat products (sliced cooked ham), dry cured meat products (sliced dry cured ham), and raw marinated meats (sliced marinated beef loin)	600 MPa (6 min, 31 °C)	HPP at 600 MPa for 6 min was an efficient method for avoiding the growth of yeasts and *Enterobacteriaceae*. HPP reduced the safety risks associated with *Salmonella* and *L. monocytogenes* in sliced marinated beef loin. Colour modifications (greyish colour) were observed in pressurized samples.	Garriga et al. (2004)
Cold smoked salmon	0.1, 150, 200 and 250 MPa	HPP with 250 MPa did not inactivate *L. monocytogenes* but significant lag phases of 17 and 10 days were observed at 5 and 10 °C. HPP with 200 MPa had a marked effect on both colour and texture.	Lakshmanan and Dalgaard (2004)
Cooked sausages	500 MPa (5 or 15 min, 65 °C), conventional heat pasteurisation (80–85 °C for 40 min), vacuum packaging	Pressurized sausages were more cohesive and less firm than heat treated sausages. Pressure treatment induced higher yield than heat treatment. Pressurized samples were preferred by sensory panelists because of their better appearance, taste and texture.	Mor-Mur and Yuste (2003)

(continued)

Table 10.4 (continued)

Products	Processing conditions	Effects	References
Frankfurters	150 and 300 MPa, salt levels (1.5 and 2.5 %)	HPP at 150 MPa decreased cook loss values and increased stability of meat emulsions at low salt levels. Texture profile analysis values were also improved after pressure treatment. Sensory panelists preferred products formulated at 1.5 % salt and pressurized at 150 MPa.	Crehan et al. (2000)
Cooked chicken meat batter	High pressure/cooking combinations (200 MPa and 400 MPa, 70 °C)	Pressurizing caused a general decrease in colour parameters. The pressurized batters formed a less compact and rigid gel matrix with better water binding properties than non-pressurized samples. High pressure to some extent protected meat protein from heat denaturation.	Fernandez et al. (1998)

for preservation: Gamma (γ) rays, X-rays or high-energy electron beams (β particles). The radionuclides approved for food irradiation include ^{137}Cs and ^{60}Co. Irradiation is often called "cold pasteurization" because of remarkable reduction of a number of dangerous microorganisms, with a negligible loss of nutrients and low degree of sensory changes (Wood and Bruhn 2000). The cellular destruction caused by disrupting genetic material in the living cell is the major effect of radiation on microorganisms in foods. However, at permitted dose levels, the effect is too low to induce any radioactivity in the food. When ionizing radiations penetrate a food, energy is absorbed. This is the 'absorbed dose' and is expressed in Grays (Gy), where:

1 Gray = 1 Joule of energy absorbed/kg food
1 Gray = 6,200 billion MeV absorbed/kg food
1 Gray = 100 Rads (or 0.022 calorie/kg of food)
1 Rad = 100 erg/g

Depending upon the objective and dose, three types of ionizing radiation treatment are **radicidation** (carried out to reduce viable non-spore-forming pathogenic bacteria, using a dose between 0.75 kGy and 2.5 kGy), **radurisation** (reduces viable spoilage organisms, using 2.5 kGy to 10 kGy radiation dose) and **radappertisation** (applied to kill both vegetative bacteria and spores, using dose levels from 30 kGy to 40 kGy).

The use of ionizing radiation for the sterilization or pasteurization of meats has been a topic of research for decades. The FDA has already approved the use of

low-dose ionizing radiation to control food-borne pathogens on meat and poultry products and to extend product shelf-life. According to this, refrigerated red meats and meat by-products may be irradiated with 4.5 kGy, while frozen meat and meat by-products may be irradiated upto 7.0 kGy. The approval includes meats of bovine, ovine, porcine, and equine sources. Ionizing radiation doses ranging from 1.5 to 3.0 kGy may be used for the decontamination of poultry. The World Health Organization has approved treatment of foodstuffs with ionizing radiation up to doses of 10 kGy (WHO 1994). The available literatures on the application of irradiation on muscle foods (Tables 10.5 and 10.6) suggest that ionizing radiation at various dose levels are effectively able to diminish the counts of spoilage and pathogenic microorganisms thus making them stable and safe without affecting product acceptability. However, irradiation is some time also associated with lipid oxidation, leading change in product's colour and development of undesired taste and flavour.

10.2.2.3 Pulsed Electric Fields (PEF)

This treatment involves the application of direct current voltage pulses for very short periods usually in the range between microseconds to milliseconds, through a material placed between two electrodes. Operation of PEF involves induction of an electric field (kV cm^{-1}) on a food placed between two electrodes and energy is delivered into the food in the form of short wave pulses (Barbosa-Canovas and Sepulveda 2005). This voltage results in an electric field, the intensity of which depends on the gap between the electrodes and the voltage delivered. Although there is not a formal definition, field strengths of $E < 0.1$ kV cm^{-1} can be considered to be low-intensity electric fields, those in the range of 0.1–1 kV $cm^{-1}$to be moderate-intensity electric fields, and those with strengths of $E > 1$ kV cm^{-1} to be high-intensity electric fields (Asavasanti et al. 2010). The increment in the permeability of a cell membrane when external electric field pulses of micro-millisecond duration are applied is well known. Depending on the intensity of the field, changes in the cell membrane can occur, which can lead to the formation of temporary or permanent pores and eventual loss of cell viability by a mechanism known as electroporation (O'Dowd et al. 2013). This mode of action by PEF treatments is also responsible for the inactivation of vegetative forms of bacteria, yeast, moulds, and some enzymes related to food quality (Barsotti and Cheftel 1999). However, bacterial and fungal spores are not inactivated by PEF treatments. Pulsed electric fields processing has the ability to effectively inactivate microbial cells, when combined with low to moderate temperatures (<50 °C), which makes it a promising alternative to conventional thermal preservation processes for liquid foods that contain heat labile bioactive or volatile components (Buckow et al. 2013). The sensitivity of microorganisms to PEF treatments depends on cell characteristics such as structure and size (Toepfl et al. 2006a). In addition, factors such as product pH, water activity (a_w), soluble solids, and electrical conductivity affect the efficiency of the technology to induce biochemical reactions and inactivate microorganisms (Aronsson and Rönner 2001).

Table 10.5 Effects of ionizing radiation on raw meat and fish products

Product	Processing conditions	Effects	References
Raw ground turkey leg, beef and pork loin patties	0 or 4.5 kGy, O_2 permeable and impermeable packaging	The cholesterol oxidation products (COPs) were detected in fresh raw meats at 0 day and after 7 days of storage which were formed in mainly aerobically packaged and irradiated raw meats. In aerobically packaged and irradiated meats, turkey leg muscles had higher COPs than beef or pork. COPs and TBARS number had a strongly positive correlation in turkey leg and pork, but cholesterol oxidation in beef proceeded in irradiated and aerobically stored samples despite of its low level of TBARS number.	Nam et al. (2001a)
Sheep/goat meat	I, 2 and 3 kGy, acid pre-sensitization with propionic, lactic and acetic acids	2 % acetic acid + 3 kGy radiation was most effective in lowering the total viable count and *B. cereus* count. Combination of treatment was found better than single treatment in lowering the dose required for destroying radio-resistant organisms in meat and extension of shelf life without any adverse effect on acceptability of meat.	Bhide et al. (2001)
PSE and DFD pork	0, 2.5 or 4.5 kGy, vacuum packaging	Irradiation increased the redness of vacuum-packaged normal, PSE and DFD pork. Irradiation increased the production of sulphur-containing volatile compounds, as well as total volatiles in all three types of pork.	Nam et al. (2001b)
Boneless, skinless chicken breast	1.0 and 1.8 kGy	Irradiation rendered the fillets free from coliforms, *E. coli*, *Salmonella* and *Campylobacter*. Irradiation doses of 1.0 and 1.8 kGy reduced the levels of aerobic bacteria up to 2 and 3 log units respectively. Texture and flavour attributes were lower for irradiated sample on day 14 than control and on 28th day, irradiated samples were less desirable with lower texture, flavour and overall acceptability scores. Degree of lipid oxidation increased as storage time and level of irradiation increased.	Lewis et al. (2002)
Minced lamb meat	2.5 or 5 kGy with a dose rate of 3 kGy/h	An increase in the free fatty acid content was observed after irradiation. Ratio of PUFA/SFA of phospholipids was decreased and TBARS number increased upon irradiation and chilled storage.	Kanatt et al. (2006a)

(continued)

Table 10.5 (continued)

Product	Processing conditions	Effects	References
Chicken breast meat	Gamma irradiation (2 and 4 kGy) with modified atmosphere packaging	The combined effect of MAP and irradiation (4 kGy) extended the storage life of fresh chicken meat by 12 days as compared to non-irradiated samples. TBARS number for all treatments remained lower than 1 mg malondialdehyde (MDA)/kg meat throughout the 25 day storage period. Irradiation resulted in a small increase of the parameter a*. Irradiation had a greater effect in extending the shelf life of chicken as compared to MAP.	Chouliara et al. (2008)
Raw beef	0, 0.5, 1.0, 1.5 or 2.0 kGy, carbon monoxide in modified atmosphere packaging (CO-MAP)	Irradiation at 0.5 and 1.0 kGy reduced 3 log units in initial Total plate counts (TPC) in aerobic and CO packaging; at 1.5 and 2.0 kGy, irradiation reduced TPC in both packaging below the detection level. Irradiation at 1.5 or 2.0 kGy resulted in total coliform counts below the detection limits during the entire storage regardless of packaging.	Ramamoorthi et al. (2009)

According to Teissié et al. (2002), PEF processing can be an effective way of inactivating microorganisms at temperatures below those used in thermal processing and enhancing mass transfer. The potential of PEF technology to enhance cell disruption presents an energy efficient and environmentally friendly alternative method of food processing (Toepfl et al. 2006b). Thus, interest in PEF as a minimal food processing technology has increased in recent years with substantial advancement in the processing of liquid foods such as milk and juices (Grimi et al. 2011; Guerrero-Beltrán et al. 2010). However, so far very limited literatures are available on the use of PEF processing in solid foods and muscle foods in particular.

Application of PEF for microbial inactivation has already been studied and it is also expected that it could also act on muscle fibres in a similar fashion and affect various quality attributes such as tenderness, water holding capacity and colour when applied to meat system. This technology when applied to muscle foods, could offer fast and cost efficient alterations to the muscle cell structure and meat tenderness, which in turn could be of major benefit to the meat industry. To date, the following four main processing concepts related to the PEF treatment of meat can be summarised (Jaeger et al. 2012):

(1) Improvement of the impregnation during dry and wet curing.
(2) Acceleration of water removal during drying.
(3) Release of intracellular enzymes to influence maturing.
(4) Modification of water binding due to microdiffusion of water binding agents.

Table 10.6 Effects of ionizing radiation on ready-to-eat meat and fish products

Product	Processing conditions	Effects	References
Ground beef patties	2 kGy, packaging (nylon/polyethylene, Saran/polyester/ polyethylene, or Saran film overwrap plus a Styrofoam tray)	Non-irradiated patties had a more pronounced beef/brothy flavour than irradiated patties. Type of packaging had no effect. Patties irradiated by gamma rays had more intense cardboardy and soured flavours, and salty and sour tastes than patties irradiated by electron beam. Irradiation of ground beef patties at medium doses can result in product that is sensorially identical to controls.	Lopez-Gonzalez et al. (2000)
Cooked pork sausage	0 and 5 kGy, aerobic, vacuum and MAP	Dose of 5 kGy reduced the N-nitrosamines at 4 week.	Jo et al. (2003)
Marinated beef rib	0, 1, 2, 3, 4 and 5 kGy, commercial refrigeration (4 °C), abusive temperature (20 °C)	At 4 °C, *S. aureus*, *B. cereus*, *S. Typhimurium* and *E. coli* were eliminated at 4 kGy but at 20 °C, 5 kGy was not enough to eliminate the pathogens. *E. coli* was the most radiation-sensitive.	Jo et al. (2004)
Ground beef patties	2.5 kGy @ 83.5 kGy/ min, ageing, L-ascorbic acid, α-tocopherol and sesamol	Irradiation reduced the redness (a*) of ground beef significantly, colour changed from bright red to a greenish brown which was countered by ascorbic acid.	Nam and Ahn (2003)
Chicken chilly, mutton shammi kababs and pork salami	1, 2 or 3 kGy	A dose of 3 kGy was found to be optimal for the shelflife extension of all three products by more than 2 weeks in chilled storage. *Staphylococcus* spp. were completely eliminated by irradiation at 2 kGy. TBARS number was increased on irradiation but it did not affect the sensory attributes of the product.	Kanatt et al. (2005)
Turkey breast rolls	0, 1.0, 1.5, 2.0, or 2.5 kGy, Potassium benzoate, sodium lactate and sodium diacetate, vacuum packaging	0.56 to 0.58 kGy led to 90 % reduction of viable cells for breast rolls. Irradiating turkey rolls added with antimicrobials, at 1.0 kGy was effective in suppressing the growth of *L. monocytogenes* for about 6 week when stored at 4 °C. No growth of *L. monocytogenes* was observed during 42 days of storage for 2.0 kGy. Low-dose irradiation (1.0 kGy) had no effect on the sensory characteristics.	Zhu et al. (2009)

Application in raw products: The impact of a PEF treatment on microstructure and texture of chicken meat and salmon was investigated (Gudmundsson and Hafsteinsson 2001) for reduction of cell size and gaping between cells. Leakage of collagen into intercellular space was detected after PEF treatment at 1.36 kV cm^{-1} and 40 pulses. Fish muscle was found to be more susceptible to gaping in comparison to chicken meat probably due to the lower content of connective tissue. No direct effect of PEF treatment on protein denaturation was found by electrophoresis so the changes in microstructure were related to permeabilisation of the cell membrane and leakage of cell fluids into extra cellular space. The effect of conventional and PEF treatment on selected quality attributes of beef *semitendinosus* (ST) was investigated (O'Dowd et al. 2013). PEF treatment that induced a temperature difference of 22 °C significantly affected weight loss of samples post treatment. The weight loss results suggested that PEF treatment may have led to slight changes in the cell membrane leading to more water loss. However, instrumental texture was unaffected by the treatments applied. PEF treatment also appeared to be suitable to reduce tumbling times while still achieving similar weight yields.

Effects of PEF treatment on the structure of animal tissues might also be utilized to enhance uptake of marinade and curing ingredients in meat and fish products. Gudmundsson and Hafsteinsson (2001) demonstrated an increase from 17 to 22 % of the weight of brine-marinated cod fillets, after the application of 300 pulses at 3 kV cm^{-1}. Toepfl et al. (2005) reported that PEF treatment of ham showed changes in tissue structure leading to weight increase after brine injection due to greater water holding capacity and less loss during cooking. PEF treatment caused porous, swamp-like structure, which holds injected brine better then untreated ham. The PEF treated ham was significantly softer and tender then untreated samples. A treatment of beef meat with PEF revealed a significant decrease of the average maximum shear force of 21.5 % thus enhancing the meat tenderness (Lopp and Weber 2005).

Application in ready-to-eat products: Toepfl (2006) investigated the impact of PEF during production of cooked ham. PEF treatment of pork haunches was performed either prior or subsequent to injection of brine. Drip loss after cooking was reduced from 22 to 12.7 % when a PEF treatment (2 kV cm^{-1}, 10 kJ kg^{-1}) was applied prior to injection of 22 % brine with 1.5 % phosphate, 2 h tumbling, 4 h curing and cooking up to 64 °C core temperature. A decrease of maximum cutting force after PEF treatment in combination with tumbling indicated a soft and tender product structure. An increase of drip loss was observed when PEF pre-treatment was applied without addition of water binding agents. An enhanced protein swelling after PEF treatment was found and assumed to be related to facilitate brine and phosphate micro-diffusion and protein-water interactions on a cellular level (Toepfl et al. 2006a). It was suggested that cell permeabilisation might have caused an improved access of phosphate to protein filaments resulting in an inclusion of free water after brine injection.

Toepfl and Heinz (2007) studied the effect of PEF treatment on ham curing time. They described that a PEF treatment of 20 kJ kg^{-1} at 4 kV cm^{-1} reduced the time necessary to remove 30 % of the meat's weight from 310 h to only 60 h.

They also found that PEF treatment of minced meat (2 kV cm^{-1}, 2 kJ kg^{-1}) and addition of starter cultures resulted in a 30 % decrease in time required to allow a pH drop to a final value of 5. Improved water binding during cooking of meat was found to occur after PEF pre-treatment due to enhanced micro-diffusion of brine and water binding agents. Same workers also reported the impact of PEF on meat tissue integrity and on the water removal in dry cured ham. Relative weight reduction and water removal were improved by PEF treatment and the drying rate was also enhanced depending on treatment intensity and salting procedure, where a treatment at 3 kV cm^{-1} and 5 kJ kg^{-1} and brine injection gave the shortest drying times. The increase in tissue permeability of the raw material was indicated by an improved ion flux resulting in an increase in conductivity after PEF treatment. A decrease in maximum cutting force for pork shoulder instantaneously after PEF treatment was reported and a more tender structure of dry cured ham was observed after maturing. The researchers assumed that the PEF-induced cell permeabilisation might have enhanced the release and, therefore, the proteolytic activity of endogenous enzymes responsible for textural changes and taste formation.

There is limited literature available on application of PEF in meat and fish products. Till now the research works are restricted to induction of structural changes in the meat to improve tenderness and enhancement of curing brine uptake as well as water holding capacity. Improvement in brine uptake through application of PEF can be helpful in reducing the time required for curing and marination.

10.2.2.4 Ultrasound Processing

Foods such as meat and meat products are complex agglomeration of various macro and micro nutrients. These products need to be processed and preserved by various techniques before final commercialization as ready-to-cook or ready-to-eat meat products. Various methods can be used for this purpose, e.g., frying, drying, and cooking. Nevertheless, many vital components and products are well known to be thermally sensitive and vulnerable to chemical, physical and microbiological changes. Losses of some compounds, low production efficiency, time and energy consuming procedures may be encountered using these conventional food processing methods. Above shortcomings have led to the search for new sustainable alternative approach in various processing operations, which typically involve less time, water and energy, such as ultrasound assisted processing. Ultrasound makes use of physical and chemical phenomena that are fundamentally different compared with those applied in conventional processing or preservation techniques. It offers a net advantage in term of productivity, yield and selectivity, with better processing time, enhanced quality, reduced chemical and physical hazards, and is environmentally friendly (Chemat and Khan 2011).

Ultrasound is a sound wave having frequency that exceeds the hearing limit of the human ear (~20 kHz). Some animals utilize ultrasound for navigation or hunting using the information carried by back-scattering sound waves. It is one of the emerging technologies that minimize processing, maximize quality and ensure the safety

of food products. Ultrasound imparts positive effects in food processing such as improvement in mass transfer, food preservation, assistance of thermal treatments and manipulation of texture and food analysis (Knorr et al. 2011). Based on frequency range, the applications of ultrasound in food processing, analysis and quality control can be categorized into low and high energy. Low power ultrasound has frequencies higher than 100 kHz at intensities below 1 W cm^2, which can be utilized for non-invasive analysis and monitoring of various food materials including meat and meat products during processing and storage to ensure high quality and safety. Low power ultrasound has been used for evaluating the composition of raw and fermented meat products, fish and poultry (Awad et al. 2012). High power ultrasound uses intensities higher than 1 W cm^2 at frequencies between 20 and 500 kHz, which are disruptive and induce effects on the physical, mechanical or chemical/biochemical properties of foods and meat products. These effects are promising in food processing, preservation and safety. Thus high power ultrasound can be utilized as an alternative to conventional food processing operations to control microstructure and modify textural characteristics, in emulsification, improvement of functional properties of different food proteins, inactivation or acceleration of enzymatic activity to enhance shelf life and quality of food products, freezing, thawing, cooking, pasteurization, tenderization etc. The advantages of the technology are versatile and profitable to the food industry, though more research efforts are still needed to design and develop efficient power ultrasonic systems that support large scale operations and that can be adapted to various processes (Gallego-Juárez et al. 2010). Till now in meat industry, high power ultrasound has found its application in tenderization, thawing, cooking and sterilization of various products.

Application in raw products: Meat tenderness is one of the most important quality attributes affecting consumer satisfaction and positive perception. Inconsistency in meat tenderness has been rated as one of the major problems faced by the meat industry. Tenderness is influenced by composition, structural organization and the integrity of skeletal muscle (Jayasooriya et al. 2004). The traditional method used for meat tenderization is mechanical pounding, which makes poorer quality meat more palatable. Use of proteolytic enzymes such as papain, bromelain, and ficin, to improve meat tenderness lacks uniformity. In this regard the use of ultrasound to improve meat tenderness can be made which causes physical disruption of materials through cavitation related mechanisms such as high shear, pressure and temperature and formation of free radicals (Jayasooriya et al. 2007). Ultrasound induces cell membrane disruption that could increase meat tenderness either directly, through the physical weakening of muscle structure, or indirectly, by the activation of proteolysis either by release of cathepsins from lysosomes and/or of Ca^{++} ions from intracellular stores so that it may activate the calpains (Boistier-Marquis et al. 1999). Improvement in meat tenderness through ultrasound can reduce the intensity and period of cooking to get the final product. It is possible to reduce traditional heat treatment by 50 % by using high-energy ultrasound (Pagán et al. 1999).

Application of ultrasound for the thawing of meat and fish indicated that acceptable ultrasonic thawing can be achieved at frequencies around 500 kHz, which conformed to a relaxation mechanism (Miles et al. 1999). Acoustic thawing can shorten

the thawing time, thus reducing drip loss and improving product quality (Li and Sun 2002). Thus, it seems that acoustic thawing is a promising technology in the food industry if appropriate frequencies and acoustic power are chosen.

Application in ready-to-eat products: Cooking of foods and meat products through conventional methods exposes surfaces to elevated temperatures leading to overcooking at the outside while interior portion still remains undercooked. This leads to a reduction in the quality of the product. Ultrasound has the ability to provide improved heat transfer characteristics, which is a key requirement to avoid such problems, and these have been utilized in cooking. Ultrasound cooking provides a significantly faster cooking rate and higher post-cooking moisture content and greater myofibrillar tenderness. An additional advantage is that ultrasound-cooked muscles have two to five times less cooking losses than those cooked by boiling and convection.

Thermal pasteurization and sterilization are the most common techniques currently used to inactivate microorganisms and enzymes in food products. Nevertheless, the effectiveness of these methods has high time and temperature requirements, which leads to deterioration of functional properties, sensory characteristics and nutritional value of food products (Lado and Yousef 2002; Piyasena et al. 2003). High power ultrasound is known to damage or disrupt biological cell walls resulting in the destruction of living cells. The ultrasonic disruption of microorganisms has been explained by acoustic cavitation and its physical, mechanical and chemical effects that inactivate bacteria and deagglomerate bacterial clusters or flocs (Joyce et al. 2003). It is supposed to be cost-efficient and environmental friendly approach for supply of safe foods to the consumer. It has also been found that the microbial mortality rate is highly dependent on ultrasound frequency, wave amplitude and volume of bacterial suspension (Raso et al. 1998). While a frequency of about 20 kHz is usually applied for microbial inactivation, the resistance of spores, Gram-positive and coccal cells to ultrasound are higher than vegetative, Gram-negative and rod-shaped bacteria (Feng et al. 2008). Thus unfortunately very high intensities are needed if ultrasound alone is to be used for permanent sterilization. However, the use of ultrasound coupled with other decontamination techniques, such as pressure, heat or extremes of pH is promising. Thermosonic, manosonic, and manothermosonic treatments are likely to be the best methods to inactivate microbes, as they are more energy–efficient and effective in killing of microorganisms.

The advantages of ultrasound over heat pasteurization include, minimized flavour loss, greater homogeneity and significant energy savings (Piyasena et al. 2003). In combination with heat, ultrasound can accelerate the rate of food sterilization, thereby lessening the duration and intensity of thermal treatment and the resultant damage (Piyasena et al. 2003). According to Lillard (1993), salmonellae attached to broiler skin were reduced upon sonication in peptone at 20 kHz for 30 min. Results of research carried out by Dolatowski and Stasiak (2002) proved that ultrasound processing was having a significant influence on microbiological contamination of meat. Thus high intensity ultrasound has found its application in meat industry to improve meat tenderness, cooking performances, nutritional value and production of safe meat and meat products.

10.2.2.5 Packaging Methods

Modified Atmosphere Packaging (MAP)

Generally, the main goal of food packaging is to maintain the quality of packaged foods during distribution. However, following the evolution of modern society and lifestyle, the significance of several functions of packaging is also shifting from one aspect to another. Consumers' preference to pre-processed products that are fresh or fresh-like, convenient, easy to prepare and without additives has promoted the development of alternative technologies for foodstuff packaging, distribution and storage. MAP of meat and meat products results in products with an improved shelf-life and quality. Typically fresh red meats are stored in modified atmosphere packages containing 80 % oxygen and 20 % carbon dioxide and cooked meats are stored in 70 % nitrogen and 30 % carbon dioxide (Smiddy et al. 2002). The oxygen, carbon dioxide and nitrogen in combination of two or three are used in various proportions to maintain the quality and stability of meat products (Table 10.7).

Bio-MAP: It is a new version of MAP where gas or gas mixture is used as a processing aid to actively deliver their functional features.

MAP with biological control: Here lactic acid bacteria (LAB) in combination with carbon dioxide enriched atmosphere packaging are used. The selected LAB should be able to stay dormant under a good temperature-controlled environment or else they would be considered spoilage microorganisms. Moreover, they should be able to initiate themselves and outgrow pathogenic microorganisms in their food matrix very rapidly when cold chain breaks.

MAP with high pressure processing: The most convenient way of combining MAP with HPP is to inject gas mixture into each individual food container and treat it under pressure, therefore avoiding the possibility of contamination after repacking. Synergistic action between HPP and gas mixture improves the microbial reduction efficiency, which in turn reduces the capital investment and operating cost of HPP.

Table 10.7 Gas mixture used in modified atmosphere packaging for meat and meat products

	Gas mixture (%)		
Product	O_2	CO_2	N_2
Red meat	60–85	15–40	–
Fresh chicken	20	30	50
Boiled meat	–	25–30	70–75
Boiled ham	–	40	60
Smoked ham	–	30	70
Cooked meat	–	30	70
Chops/slices	69	20	11
Fresh fish	25	60	15
Smoked fish	–	15	85

Ucherek (2004), Ščetar et al. (2010)

Table 10.8 Potential applications of active packaging in meat and fish products

Types of packaging	Food item
O_2-scavenger	Salami, smoked meats, fresh and frozen fish, sausages
CO_2-scavenger	Beef jerkey, poultry products
CO_2-emitter	Fresh meat and fish
Moisture scavenger	Meat, frozen fish and seafood
Ethanol emitter	Semi-dry fish and frozen fish

Modified from Vermeiren et al. (1999)

Table 10.9 Potential applications of antimicrobial packaging in meat and fish products

Antimicrobials	Food item
Organic acids and their salts	Fresh meat, sausage, ham, chicken
Bacteriocins, enzymes, chelating agents	Fresh meat, sausage, ham, chicken, fish, shellfish
Sanitizers	Fresh meat, chicken, fish, shellfish
Volatile essential oils	Fresh and processed meats, ground beef, chicken
	Nuggets, fish, shellfish, dried fish
Spices	Fresh and processed meats, fresh and cooked chicken, fish, shellfish, dried fish
Probiotics	Fresh and processed meats, cured meats

Modified from Han (2005)

MAP with irradiation: The role of gas atmosphere for irradiation is more of quality enhancement. During irradiation process, in under normal air surrounding, it reacts with oxygen and creates ozone and other free radicals that could oxidize food and introduce off-odour and discolouration. Introduction of inert gas in the package can protect irradiated food from being oxidized.

Active and Intelligent Packaging

Active packaging is an intelligent or smart system that involves interactions between package or package components and food or internal gas atmosphere and complies with consumer demands for high quality, fresh-like, and safe products. Active packaging extends the shelf life of foods, maintain their nutritional quality, inhibit the growth of pathogenic and spoilage microorganisms, prevent and/or indicate the migration of contaminants, and display any package leaks present, thus ensure food safety (Ozdemir and Floros 2004). Oxygen scavengers, carbon dioxide emitters/absorbers, moisture absorbers, ethylene absorbers, ethanol emitters, flavour releasing/absorbing systems, time-temperature indicators, and antimicrobial containing films are some of the important examples of active packaging (Tables 10.8, 10.9, and 10.10).

Effect of two commercial oxygen scavengers (Ageless®FX-100 and FreshPax®R-2000), in conjunction with controlled atmosphere packaging was

Table 10.10 Antimicrobial food packaging systems

Antimicrobial agents	Packaging materials	Food	Microorganisms	References
Benzoic acids	PE	Tilapia fillets	Total bacteria	Huang et al. (1997)
Nisin	PE	Beef	*B. thermosphacta*	Siragusa et al. (1999)
Nisin, lacticins	LDPE, polyamide	Beef	Total aerobes, coliform	Kim et al. (2002)
Nisin, EDTA	PE, PE-PE oxide	Beef	*B. thermosphacta*	Cutter et al. (2001)
Nisin, citrate, EDTA	PVC, nylon, LLDPE	Chicken	*S. Typhimurium*	Tatrajan and Sheldon (2000)
Nisin, lauric acid	Soy protein	Turkey bologna	*L. monocytogenes*	Dawson et al. (2002)
Grapefruit seed extract	LDPE, nylon	Ground beef	Total aerobes, coliform bacteria	Ha et al. (2001)
Cinnam-aldehyde, eugenol, organic acid	Chitosan	Bologna, ham	Enterobaceria, LAB, *L. sakei*, *Serratia. spp.*	Ouattara et al. (2000a, b)
Horseradish oil	Paper in pouch	Ground beef	*E. coli* O157:H7	Nadarajah et al. (2002, 2003)
Horseradish extract and *Lb. reuteri* (probiotics)	PE/EVOH/ PET pouch	Ground beef	*E. coli* O157:H7	Muthukumarasamy et al. (2003)
Allyl isothiocyanate	PE film/pad	Chicken, meats, smoked salmon	*E. coli*, *S. enteritidis*, *L. monocytogenes*	Takeuchi and Yuan (2002)
Carbon monoxide	Modified atmosphere packaging	Pork chops	Total bacteria, LAB	Krause et al. (2003)
Triclosan	LDPE	Chicken breast	*L. monocytogenes*, *S. aureus*, *S. enteritidis*, *E. coli* O157:H7	Vermeiren et al. (2002)

examined on the discolouration of *M. psoasmajor* in master packs filled with nitrogen and stored at 1 ± 0.5 °C. Steaks packaged without oxygen scavengers had more discolouration and higher proportions of metmyoglobin when compared to steaks packaged with oxygen scavengers (Tewari et al. 2001). Fresh pork sausages stored in 20 % carbon dioxide and 80 % nitrogen with an oxygen scavenger (Ageless®FX-40) for up to 20 days at 2 ± 1 °C had reduced psychrotrophic aerobe counts and an extended shelflife in terms of colour and lipid stability (Martínez et al. 2006). Carbon dioxide generators are mainly used for meat preservation because of their inhibitory activity against a range of aerobic bacteria and fungi. In case of meat and poultry preservation, high carbon dioxide levels (10–80 %) are desirable as it inhibits

surface microbial growth and thereby extends shelflife. Carbon dioxide has differential effects against microorganisms where aerobic bacteria as *Pseudomonas* are inhibited by moderate to high levels (10–20 %) while microorganisms as lactic acid bacteria can be stimulated by CO_2. Moreover, pathogens such as *C. perfringens*, *C. botulinum* and *L. monocytogenes* are minimally affected by CO_2 levels lower than 50 %.

Antimicrobial packaging is another promising form of active packaging especially for meat products. Unhygienic post-processing handling of meat products mainly results in surface contamination thus, attempts have been made to improve their safety and to delay spoilage through use of antibacterial sprays or dips and antimicrobial packaging. Antimicrobial food packaging materials extend the lag phase and reduce the growth phase of microorganisms (Han 2000).

10.2.3 Minimal Processing with Biopreservation and Natural Antimicrobials

In the production of food such as meat and meat products it is crucial that proper measures are taken to ensure the safety and stability of the product during its entire storage and distribution. Nowadays consumers too showing their interest towards better quality, low in preservatives or preservative-free, safe but mildly processed meat products with extended shelflife. Additionally the utilization of chemical or synthetic preservatives is being challenged by consumers because of the health issues associated with several food additives. Therefore, exploration of the additional options like biopreservation and natural antimicrobials has been started with the help of antimicrobials from natural and microbial sources. These agents supposed to minimize the intensity of thermal or other stringent treatments required to provide safe and stable meat and meat products. The preservation of foods using their natural or controlled microbiota or their antimicrobial metabolites like bacteriocins has been termed as bioprotection or biopreservation. The main purpose of biopreservation is extension of shelf life as well as the enhancement of food safety. Bacteriocins and bacteriocin-producing LAB strains are of great interest since they can more easily earn the status of Generally Recognized As Safe (GRAS) and their products may be regarded as natural biopreservatives (Stiles 1996), satisfying the consumer demand for foods that are naturally preserved, hygienically safe and also nutrient-rich and minimally processed. Bacteriocins are a heterogeneous group of antibacterial proteins that vary in spectrum of activity, mode of action, molecular weight, genetic origin and biochemical properties. The use of enterocins in the preservation of meat, poultry and fish products has great potential especially when the nisin is less effective as a preservative in meat products and it also has reduced activity against *L. monocytogenes*. The use of broad-spectrum enterocins such as AS-48, or the strongly anti-listerial enterocins such as A and B have potential in meat preservation (Khan et al. 2010).

Natural compounds, such as essential oils from herbs and spices, herbal extracts, oleoresins, chitosan, lysozyme and lactoferrin have also been investigated for their antimicrobial activities and can be used to replace chemical preservatives to obtain 'green label' products. Spices are primarily used to add flavour to foods but some of them are also known for antioxidant and antimicrobial properties. The antimicrobial activity of spices lies in their essential oil, which consist of a complex mixture of esters, aldehydes, ketones, and terpenes. The antimicrobial activity of spices is strongly dependent on the composition of the essential oil therefore; the ability of inhibiting gram-positive or gram negative bacteria are determined by these compositional factors. Essential oils can be used directly into the food providing an additional functionality, such as antimicrobial and flavouring agent (Señorans et al. 2003).

Biopreservation of raw products: Nykänen et al. (2000) observed that both nisin and sodium lactate inhibited the growth of *L. monocytogenes* in smoked fish, but the combination of the two compounds was even more effective. James and Johnson (2001) observed that garlic enhanced the activity of nisin to inhibit or kill *L. monocytogenes* at 8 °C in chicken. While working with raw beef, Ariyapitipun et al. (1999) found that 2 % low molecular weight polylactic acid, 2 % lactic acid and the combinations of each acid and nisin significantly lowered the microbial population of psychrotrophic aerobic bacteria, psychrotrophic, and mesophilic *Enterobacteriaceae*, *Pseudomonas*, and *Lactobacillus* compared with the untreated control, water or nisin alone. Further, Ariyapitipun et al. (2000) observed that in vacuum packaged beef above treatments along with vacuum packaging and refrigeration temperature, succeeded to inhibit the growth of *L. monocytogens* Scott A during storage up to 42 days.

Kim et al. (2002) reported the influence of the bacteriocin-coated (nisin or lacticin NK24) films on quality preservation and shelflife extension of fresh oysters and ground beef. Compared to plain low density polyethylene film, plastic films with incorporated bacteriocins slowed down microbial growth on both the products and contributed in some degree to the preservation of chemical quality and extended shelflife significantly. The effects of the antimicrobial films on the suppression of coliform bacterial growth were more pronounced at 10 °C than at 3 °C, while the effects on total aerobic bacteria were consistently evident at both temperatures. Effect of pentocin 31-1 was studied as a biopreservative in storage of tray packaged chilled pork. Results showed that pentocin 31-1 could substantially inhibit the accumulation of volatile basic nitrogen (VBN) and generally suppress the growth of microflora, especially *Listeria* and *Pseudomonas*, during chilled pork storage (Zhang et al. 2010).

Biopreservation of ready-to-eat products: In a study with fresh pork sausage, Scannell et al. (2000) observed that combination of organic acids with either lacticin 3147 or nisin enhanced the activity against *Salmonella Kentucky* and *L. innocua* and was particularly effective in the inhibition of *C. perfringens*. In cold-smoked salmon, Katla et al. (2001) found that sakacin P had an initial inhibiting effect on growth of *L. monocytogenes* while cultures of *L. sakei* had a bacteriostatic effect. When *L. sakei* culture was added to salmon together with sakacin P, a bacteriocidal effect

against *L. monocytogenes* was observed. Lahti et al. (2001) prepared a sausage batter which was inoculated with various levels of *E. coli* O157:H7 and *L. monocytogenes* serovar 4b and fermented using starter cultures A (*S. xylosus* DD-34 with bacteriocin-producing *Pediococcus acidilactici* PA-2 and *L. bavaricus* MI-401) and B (*S. carnosus* MIII with *L. curvatus* Lb3). The numbers of *E. coli* O157:H7 decreased more using starter B than starter A but the organism was not eliminated. On the other side, *L. monocytogenes* decreased more rapidly in the high-inoculum sausages produced with starter A but no significant difference was detected between the starters in the medium-inoculum sausages.

An effect of nisin added to zein film coatings on ready-to-eat chicken against *L. monocytogenes* was observed (Janes et al. 2002). It was found that zein film coatings with nisin can prevent the growth of *L. monocytogenes* on ready-to-eat chicken. Dawson et al. (2002) incorporated lauric acid (8 %, w/w) and 2.5 % pure nisin (4 %, w/w) singly and together into thermally compacted soy films. These biocide-impregnated films were compared with control films for inhibition of *L. monocytogenes* on turkey bologna surface. Nisin films reduced cell numbers on turkey bologna from 10^6 to 10^5 after 21 days, as did films containing nisin and lauric acid. Films with lauric acid alone reduced *L. monocytogenes* by 1 log on turkey bologna after 21 days.

The bacteriocin producing *Leuconostoc carnosum* 4010 was used to inhibit the growth of *L. monocytogenes* in sliced meat product, saveloy (Jacobsen et al. 2003). The methods using the living protective culture added to the sliced gas packed meat product were more effective in preventing growth of *L. monocytogenes* than the use of the partially purified leucocins 4010 or bacteriocin produced during fermentation before heat treatment of the saveloy. The application method giving the highest reduction in *L. monocytogenes* used nozzles for sprinkling the protective culture on all surfaces of each slice of the meat product. The live cells of the bacteriocin producing *Lc. carnosum* 4010 was found to be the most efficient method for inhibiting the growth of *L. monocytogenes* in cooked, sliced and gas packed saveloy stored at 5 and 10 °C for 4 weeks.

The effects of pediocin AcH bound to its heat-killed producer cells *Lactobacillus plantarum* WHE 92 against *L. monocytogenes* ATCC 7644 and (spoilage) lactic acid bacteria on sliced cooked sausage was investigated (Mattila et al. 2003). The pediocin preparation had no effect either on the growth of lactic acid bacteria, on the pH value or on the flavour of vacuum-packed sliced sausage during 21 days of storage compared to control. However, during 6 days of storage, the number of *L. monocytogenes* decreased from the initial level of 2.7 log cfu/g sausage to <2 log cfu/g, while on the control sausages the number of *L. monocytogenes* remained at the inoculated level. It was also noticed that the pediocin preparation was not efficient enough to kill all *L. monocytogenes*. The effectiveness of enterocin AS-48 has been tested against *L. monocytogenes* and *S. aureus* in model sausages. The results indicated that approximately 40 μg/ml of crude bacteriocin preparation was required for complete inhibition of the pathogens during storage period of 9 days. The addition of producer strains (10^7 cfu/g) during preparation of model sausages also helped in controlling the growth but complete inhibition could not be achieved

(Ananou et al. 2005a, b). Further the effectiveness of enterocin AS-48 alone or in combination with chemical preservatives and/or heat against *L. monocytogenes* and *S. aureus* in a cooked ham model system was tested by same workers (Ananou et al. 2010). AS-48 alone was effective against *L. monocytogenes* at 5 and 15 °C, but it was not sufficient to avoid regrowth of *Listeria* during the 60 days storage. However, combination of AS-48 with nitrite/nitrate, pentasodium tripolyphosphate, sodium benzoate or potassium sorbate improved the effectiveness and the most suitable combination was AS-48-nitrite/nitrate (0.007 %) that reduced *Listeria* below detection level from the beginning to end of storage. Much more resistant, *S. aureus* was also inhibited by AS-48 alone at 5 °C, and especially in combinations with nitrite/nitrate, pentasodium tripolyphosphate, sodium lactate and sodium acetate. Best results against both the pathogens were obtained when sodium pyrophosphate was applied in combination with 60 μg g^{-1} AS-48. Sub-lethal heat (60 °C, 2 min) clearly increased AS-48 activity against both *Listeria* and *Staphylococcus*.

In another trial enterocin CCM 4231 was added (12,800 AU/g) during preparation of dry fermented Hornad salamis artificially inoculated with 1 % of a *L. monocytogenes* culture, containing approximately 10^8 cfu/ml. After 3 weeks of ripening, the count of *L. monocytogenes* was 10^4 cfu/g in samples with added enterocin as compared with 10^7 cfu/g in control samples (Lauková et al. 1999). The anti-listerial effect was examined for enterocins A and B in selected meat and meat products (cooked ham, minced pork meat, deboned chicken breasts, pate and slightly fermented sausages) stored at 7 °C (Aymerich et al. 2000). A reduction in the counts of artificially inoculated *L. innocua* was observed in all the samples during storage, as compared with control treatments where the counts either increased or remained constant during storage. Similar anti-listerial activity was also noted for enterocins 1071A and 1071B, produced by *E. faecalis* BFE 1071, in fish spread. More than 90 % reduction in the counts of *L. innocua* was found after 21 days of storage under refrigerated conditions, when compared with untreated control (Dicks et al. 2006). The effect of different nisin concentrations on *L. monocytogenes* in experimentally contaminated Turkish fermented sausage (*sucuk*) was observed (Hampikyan and Ugur 2007). No *L. monocytogenes* surviving cells were detected in groups which contained 100 μg/g and 50 μg/g nisin at day 20 and 25, respectively.

Natural antimicrobials in raw products: Lactoferrin, an iron binding protein, has the potential to be an antimicrobial in foods (Naidu 2002). An investigation was made to observe the potential of "activated lactoferrin" as a spray treatment on carcasses or on chilled primal cuts as a microbial blocking agent. It was found that activated lactoferrin has activity against an array of bacterial pathogens including *E. coli* O157:H7, *L. monocytogenes*, *Salmonella* spp., and *Campylobacter*, as well as some meat spoilage organisms including *Pseudomonas* spp. and *Klebsiella* spp. (Naidu 2002). Lysozyme is one of the most frequently used antimicrobial enzymes and shows antibacterial activity, mainly on Gram-positive bacteria by splitting the bonds between N-acetylmuramic acid and N-acetylglucosamine of the peptidoglycan in cell walls (Güçbilmez et al. 2007). The antimicrobials lysozyme, nisin, and mixtures of the two were used to control the growth of the meat-borne spoilage

bacteria, *B. thermosphacta* B2 and *Carnobacterium* spp. 845 (Nattress et al. 2001). An estimated surface concentration of 130 μg/cm^2 of each of the antimicrobials effectively inhibited *B. thermosphacta* B2 on inoculated cores of fat and lean pork tissue when the cores were incubated in vacuum packages for 6 weeks at 2 °C. Nisin and mixtures of the two antimicrobials inhibited *Carnobacterium* spp. 845 so that its numbers were at least 3 log units lower than untreated samples after 26 and 27 days incubation for APT broth and pork juice, respectively. On lean pork tissue, numbers of *Carnobacterium* spp. 845 were significantly lower when 260 μg/cm^2 of a 1:3 (w/w) ratio of nisin to lysozyme was introduced to the cores.

A mixture of lysozyme and nisin at a ratio of 3:1 (w/w) and at a surface concentration of approximately 260 μg/cm^2 was effective in controlling the growth of lactic acid bacteria (Nattress and Baker 2003). Sensory evaluation of the loins showed no difference between treated and untreated samples, but aerobically displayed chops treated with antimicrobial had more prevalent off-odours and reduced odour acceptability than untreated samples. According to Branen and Davidson (2004) when lysozyme is combined with ethylenediaminetetraacetate (EDTA), the antibacterial spectrum increases significantly and it is effective against Gram negative organisms. The inhibitory effect of Microgard™ 100, Microgard™ 300, nisin, Alta™ 2002, Perlack 1902, sodium lactate and essential oil of mustard on experimentally inoculated microorganisms was screened in an acidified chicken meat model (Lemay et al. 2002). Sodium lactate was found most effective against *B. thermosphacta*. Essential oil of mustard lowered the aerobic mesophilic bacteria and lactic acid bacteria significantly with respect to control after 2 days of storage. The other antimicrobial agents tested had no significant effect on the aerobic mesophilic bacteria, *E. coli*, *B. thermosphacta* and lactic acid bacteria counts, when compared to the control.

The antilisterial efficacy of chitosan-coated plastic films alone or incorporating five generally recognized as safe (GRAS) antimicrobials viz., nisin, sodium lactate (SL), sodium diacetate, potassium sorbate (PB) and sodium benzoate (SB) in ham steaks stored at room temperature for 10 days was evaluated (Ye et al. 2008a). Incorporating antimicrobials into chitosan-coated plastic films slowed down or inhibited the growth of *L. monocytogenes*. The chitosan-coated plastic film containing SL was the most effective antimicrobial film against *L. monocytogenes*. The film showed excellent longterm antilisterial effect with the counts of *L. monocytogenes* being slightly lower than the initial inoculum.

The antimicrobial effect of thyme essential oil (EO), nisin, and their combination, on *E. coli* O157:H7 was examined in both tryptic soy broth (TSB) and minced beef meat (Solomakos et al. 2008). A 0.6 % of EO was found suitable for the product and further examined against the pathogens in minced meat. Treatment of minced beef meat with EO showed an inhibitory activity against *E. coli* O157:H7 during storage at 10 °C, but not at 4 °C. Treatment of minced beef meat or TSB with nisin did not show any antibacterial activity against *E. coli* O157:H7. The combination of 0.6 % EO and 500 or 1,000 IU/g nisin showed an additive effect against the pathogen, which was higher during storage at 10 °C than at 4 °C. The inhibitory effect of essential oils (EOs) extracted from the aerial parts of cultivated *Salvia officinalis* L. and the berries of *Schinus molle* L. were evaluated against two foodborne

pathogens belonging to *Salmonella* genus in minced beef meat (Hayouni et al. 2008). The antibacterial activities of both EOs in minced beef meat were clearly evident however; their addition had notable effects on the flavour and taste of the meat at concentrations more than 2 % for *S. molle* and 1.5 % for *S. officinalis*. One solution to the above mentioned problem may be the use of combinations of different food preservation systems.

Inhibition of *E. coli* O157:H7, *S. typhimurium*, and *L. monocytogenes* by grape seed extract (ActiVin) and pine bark extract (Pycnogenol) and the effect of these natural extracts on the oxidative stability of raw ground beef were studied (Ahn et al. 2004). The numbers of *E. coli* O157:H7, *L. monocytogenes*, and *S. Typhimurium* declined in raw ground beef treated with 1 % Pycnogenol after 9 days of refrigerated storage. ActiVin (1 %) and oleoresin rosemary (1 %) resulted in an approximately 1-log cfu/g reduction in the populations of all three pathogens after 9 days. It was suggested that these natural extracts have potential to be used with other preservative methods to reduce pathogenic numbers, lipid oxidation, and colour degradation in ground beef.

Natural antimicrobials in ready-to-eat products: The effect of natural antimicrobials such as EDTA, lysozyme, rosemary and oregano oil and their combinations, on the shelflife of semi cooked coated chicken fillets stored under vacuum packaging was reported by Ntzimani et al. (2010). Among the antimicrobial combinations examined, the treatments vacuum packaging, EDTA lysozyme solution and rosemary oil combination and vacuum packaging, EDTA lysozyme solution and oregano oil combination were the most effective against the growth of Gram-negative, Gram-positive bacteria, and to a lesser extent on yeasts and produced a shelflife extension of 7–8 days, as compared to the control samples.

Efficacy of chitosan-coated plastic films containing nisin, sodium lactate (SL), sodium diacetate, potassium sorbate (PB) and sodium benzoate (SB) against *L. monocytogenes* on cold-smoked salmon was observed (Ye et al. 2008b). The film incorporating SL was the most effective, completely inhibiting the growth of *L. monocytogenes* during 10 days of storage. *L. monocytogenes* in samples packaged in the other four antimicrobial films grew, but the increase in counts was lower than the control. The workers also found that chitosan-coated plastic films with 4.5 mg/cm^2 SL, 4.5 mg/cm^2 SL–0.6 mg/cm^2 PS and 2.3 mg/cm^2 SL–500 IU/cm^2 nisin were the most effective and completely inhibited the growth of *L. monocytogenes* on smoked salmon for at least 6 weeks.

The effect of rosemary extract, chitosan and α-tocopherol, added individually or in combination, on microbiological parameters and lipid oxidation of fresh pork sausages was investigated (Georgantelis et al. 2007). Chitosan addition showed significant inhibition of microbial growth, while the lowest microbial counts were obtained in the samples containing both chitosan and rosemary, indicating a possible synergistic effect. Shelf life of samples containing chitosan was almost doubled compared to the remaining samples.

Studies have shown the antimicrobial activity of oregano and two of its major components, carvacrol and thymol (Exarchou et al. 2002; Seaberg et al. 2003; Ahn et al. 2004). Cranberry fruit contains a wide range of phenolic phytochemicals, and

has been historically associated with positive health benefits (Vattem et al. 2005). It is now believed that these positive health benefits, including antimicrobial effects, are a result of the constituent phenolic phytochemicals such as phenolic acids, biphenolics such as ellagic acid, flavanoids and proanthocyanidins (Vattem and Shetty 2005). Xi et al. (2011) showed that cranberry powder at 1 %, 2 % and 3 % resulted in 2–4 log cfu/g less growth of *L. monocytogenes* compared to the control with nitrite alone. Other natural compounds, such as cherry powder, lime powder and grape seed extract, also provided measureable inhibition to *L. monocytogenes* when combined with cranberry powder. A study has shown that synergies of oregano and cranberry water extracts give enhanced hurdle for *L. monocytogenes* control, both in meat and fish systems (Lin et al. 2004). The efficiency of water soluble phenolic extracts of oregano and cranberry in combination with sodium lactate was evaluated for control of *L. monocytogenes* in both broth and cooked meat (Apostolidis et al. 2008). The results indicated that the combination of water soluble extracts of oregano and cranberry, at a ratio of 1:1 and a concentration of 750 ppm, with 2 % sodium lactate had the best inhibitory effect in the tested strain. The works conducted by various researchers on application of bacteriocins and bacteriocins producing cultures as well as different natural antimicrobials shows that at a suitable levels and combinations, they can effectively inhibit the growth of spoilage and pathogenic microorganisms in meat and meat products.

10.2.4 Minimal Processing with Hurdle Technology

Hurdle technology has an immense potential to improve the microbiological stability, sensory characteristics as well as nutritional properties of foods and meat products. It encompasses all factors used for food preservation and can be defined as a combined application of various technologies, factors and/or agents (hurdles) to food/meat in order to maximize the preservation effect (Rodríguez-Calleja et al. 2012). The effects of hurdles on meat quality can be positive or negative depending on how they are being applied and at what level. Thus various hurdles should be applied very judiciously in an intelligent way to reduce the intensity of treatments. An intelligent combination of hurdles could achieve an extension of shelflife or an improvement in safety or sensory properties while maintaining meat quality. In industrialized countries, the hurdle technology approach is currently of most interest for minimally processed foods which are mildly heated or fermented (Leistner 2000), and for underpinning the microbial stability and safety of foods. In developing countries like India and China, the application of hurdle technology for foods developed stable, safe, and tasty products without refrigeration storage. It is paramount importance and receiving much interest, particularly intentional hurdle technology.

Application in raw products: Uncured turkey breast, commercially available with or without a mixture of potassium lactate and sodium diacetate was inoculated with *L. monocytogenes*, packaged in two types of bags to simulate contamination after a

lethal processing step at the plant and contamination during slicing/handling at retail or home (Lianou et al. 2007). Both sets of bags were stored aerobically at 7 °C for 12 days to simulate home storage. *L. monocytogenes* populations were significantly lower during storage in turkey breast containing a combination of lactate and diacetate compared to product without antimicrobials under both contamination scenarios.

Antilisterial activity of nisin (Nisaplin), alone (400 and 800 IU/g) and in combination with 2 % sodium chloride was observed in raw buffalo meat mince (Pawar et al. 2000). The growth of *L. monocytogenes* in the treated groups was significantly inhibited compared to the control group. The degree of inhibition increased with increasing concentration of nisin and decreasing storage temperature. Addition of 2 % sodium chloride in combination with nisin increased the efficacy of nisin. The effect of nisin and nisin/EDTA followed by vacuum packaging on the reduction of *B. thermosphacta* and *S. Typhimurium* counts on beef was investigated (Tu and Mustapha 2002). Growth of *B. thermosphacta* was completely inhibited by nisin and nisin/EDTA. However, neither treatment showed significant effects against *S. Typhimurium*. It was suggested that nisin or nisin/EDTA treatment, followed by vacuum packaging under refrigerated conditions could increase the shelf life of fresh beef.

Application in ready-to-eat products: Juncher et al. (2000) found that two combinations of hurdles, 2.0 % lactate + 0.5 % acetate or 2.0 % lactate + 0.25 % gluconodelta-lactone (GdL), were able prevent growth of *L. monocytogenes* inoculated onto sliced *saveloys* manufactured with 60 or 150 ppm nitrite. Changes in red colour and lipid oxidation were low during storage at 5 °C and unaffected by the storage condition. A combination of 2.0 % lactate + 0.25 % GdL improved oxidative stability and led to significantly lower thiobarbituric acid reactive substances (TBARS) and higher redness values. Levels of nitrosamines were also low with values near the detection level. Although observed differences were small, members of a trained sensory panel were able to distinguish control and treated product.

Karthikeyan et al. (2000) studied the extension of shelf life of the highly perishable Indian traditional meat product, chevon (caprine) *keema*, through the application of hurdle technology. The hurdles used were water activity and pH as variable hurdles while vacuum packaging, preservatives and heat treatment as constant hurdles. The product with a_w at 0.90, pH at 5.8 was found most suitable. There was a decrease in the growth rate of aerobic and anaerobic counts and complete inhibition of *S. aureus*. It was also found that sensory scores for hurdle treated *keema* declined upon storage and the product was well accepted up to the 3rd day and fairly accepted up to 5th day whereas the *keema* prepared by the traditional method was acceptable only on the first day. The mutton curry was preserved by hurdle technology, employing various hurdles like water activity, pH, preservative, high temperature, low temperature and oxido-redox potential to obtain convenience intermediate moisture product (Das and Radhakrishna 2001). The product having 37.68 % moisture, 33.15 % fat and pH at 5.58 was found stable for more than 4 months at ambient temperature of 27 ± 2 °C and more than 6 months at refrigerated temperature of 3 ± 2 °C.

The product had a longer storage life at refrigeration than at ambient temperature and in paper-foil-polyethylene pouch than in polypropylene pouches.

A reduction in the nitrite content in hot dogs using hurdle technology without sacrificing product safety and quality was reported (Jafari and Emam-Djomeh 2007). The water activity and pH of the hot dog were adjusted to 0.95 and 5.4 and the sausages were kept at chilled temperature (>3 °C but ≤10 °C) throughout their shelf life. There was a decrease in total aerobic counts in hurdle treated hot dogs (with 50 ppm nitrite), compared to the control (with 120 ppm nitrite), whereas *C. perfringens* counts and *C. botulinum* detection were the same in both hurdle treated and control samples. Sensory characteristics of control and treated product remained similar.

Shelf stable pork sausages were developed using hurdle technology and their quality was evaluated during ambient temperature (37 ± 1 °C) storage (Thomas et al. 2008a). Various hurdles incorporated were low pH, low water activity, vacuum packaging and post package reheating. Dipping in potassium sorbate solution prior to vacuum packaging was also studied. Hurdle treatment reduced oxidative and microbiological quality deterioration during storage as indicated by pH, TBARS, tyrosine values and microbial counts. The pH, a_w and reheating hurdles inhibited yeast and mould growth up to day 3, while additional dipping in 1 % potassium sorbate solution inhibited their growth throughout the 9 days storage. Despite low initial sensory appeal, the hurdle treated sausages had an overall acceptability in the range 'very good' to 'good' up to day 6. The suitability of hot-boned pork and pork fat for processing shelf-stable pork sausages using hurdle technology was also evaluated by the same workers (Thomas et al. 2008b). Hot-processed sausage received higher total plate counts while lactobacillus counts were high in cold-processed product throughout the storage period. Sensory evaluation revealed that hurdle-treated pork sausages from hot-boned pork were equally suitable as those from cold-boned pork up to day 6 at ambient temperature.

The effectiveness of various hurdles such as irradiation, reduced water activity, and vacuum packing in preventing the growth of *C. sporogenes*, *S. aureus* and *B. cereus* in ready-to-use shelf stable meat products was tested (Chawla and Chander 2004). Radiation treatment (2.5 kGy) resulted in complete elimination of inoculated 10^6 cfu of *S. aureus* and *B. cereus* but not of *C. sporogenes*. The water activity of 0.85 and vacuum packaging of products prevented the growth of all three organisms inoculated into these samples during 3 months of storage at room temperature. Irradiation also successfully inactivated yeast and moulds which otherwise grow in the kababs after 2 months of storage. Kanatt et al. (2006b) developed a process for the preparation of shelfstable, ready-to-eat shrimps using a combination of reduced water activity (0.85 ± 0.02), packaging and γ-irradiation (2.5 kGy). Microbiological analysis of the product revealed a dose dependent reduction in total viable count and *Staphylococcus* species. In non-irradiated samples a visible mould growth was seen within 15 days of storage at ambient temperature (25 ± 3 °C). No significant changes in textural properties and sensory qualities of the product were observed on radiation treatment and they were microbiologically safe and sensorially acceptable even after 2 months of storage at ambient temperature.

Effects of adding vinegar and/or sake as preservation hurdles to a seasoned Korean beef product, vacuum packed in gas barrier plastic and pasteurized was reported (Jang et al. 2006). A combination of vinegar and sake improved the microbial stability of the product at 8 and 20 °C, while added vinegar and/or sake did not improve the sensory quality of the product. The vinegar and sake combination produced significantly inferior initial quality in taste and overall acceptability.

Ham and bologna sausages were prepared with or without addition of 500 ppm lysozyme: nisin (1:3) and 500 ppm EDTA (Gill and Holley 2000). Sausages were inoculated with one of; *B. thermosphacta*, *E. coli* O157:H7, *L. sakei*, *L. curvatus*, *Leuconostoc mesenteroides*, *L. monocytogenes*, *S. Typhimurium*, *Serratia grimesii* or *Shewanella putrefaciens*, vacuum packed and stored for 4 weeks at 8 °C. Inhibitor treatment reduced initial populations of *B. thermosphacta* and *Lc. mesenteroides* on both meats. Treatment of ham and bologna prevented growth of these microbes for various durations as compared to control.

Samelis et al. (2005) reported the effect of dipping solutions of nisin with or without organic acids (lactic or acetic acid) or salts (sodium acetate or diacetate and potassium benzoate or sorbate) on *L. monocytogenes* introduced in sliced cooked pork bologna before vacuum packaging and storage at 4 °C for 120 days. Nisin reduced *L. monocytogenes* by 1.0–1.5 log cfu/cm^2 at day 0 followed by a listeriostatic effect for 10 days. Nisin in combination with 3 or 5 g/100 ml acetic acid or sodium diacetate or 3 g/100 ml potassium benzoate, applied individually or as mixtures, did not permit growth before day 90.

The antimicrobial effectiveness of lysozyme, nisin, and EDTA combination treatments (Mix_1: 250 ppm lysozyme, 250 ppm nisin, 5 mM EDTA; Mix_2: 500 ppm lysozyme, 500 ppm nisin, 5 mM EDTA) on bacterial growth of ostrich patties packaged in air, vacuum, and two different modified atmospheres (MAP_1: 80 % O_2, 20 % CO_2; MAP_2: 5 % O_2, 30 % CO_2, 65 % N_2) was evaluated (Mastromatteo et al. 2010). The growth of total viable counts and lactic acid bacteria were strongly inhibited by the antimicrobial treatments in all the running time (Inhibition Index >97 %) whereas for *Enterobacteriaceae* and *Pseudomonas* spp. lower inhibition indices from 12 % to about 28 % were observed. The lipid oxidation was more pronounced in the control respect to the treated meat patties. Moreover, the mixture at low concentration of lysozyme and nisin showed the best antioxidative effect. However, high concentrations of lysozyme and nisin showed the greatest colour loss. Influence of nisin and butylated hydroxyanisole (BHA) on the shelf life of vacuum packed buffalo meat sausage having a_w 0.88 for 7 days at ambient conditions (35 ± 2 °C, 70–80 % RH) was reported (Sureshkumar et al. 2010). Thiobarbituric acid reactive substances number of product with 100 ppm BHA and with 100 ppm each BHA and nisin were found lower. Nisin and BHA together exhibited a significant inhibitory effect on total viable count, staphylococcal, streptococcal and anaerobic counts. Product with nisin and BHA had a better appearance, flavour, texture and overall acceptability scores up to 5 days.

The effectiveness of selected starter cultures and high hydrostatic pressure (400 MPa) after ripening of slightly fermented sausage was evaluated by Garriga et al. (2005). Starter cultures were able to control the growth of *L. monocytogenes*,

Enterobacteriaceae, *Enterococcus* and the biogenic amine content. *Salmonella spp*. counts decreased significantly during ripening independently of the starter culture but the HHP was necessary to ensure absence of *Salmonella* in final products. The combined effect of high pressure processing and ripening on foodborne pathogens in low-acid fermented sausages (*fuet* and *chorizo*) was evaluated (Marcos et al. 2005). *Salmonella* counts decreased in all studied sausages during ripening, however the application of HPP (300 MPa for 10 min at 17 °C) as an additional hurdle to the ripening process produced a greater decrease in the *Salmonella* population, showing lower counts (3 MPN/g) in ripened sausages.

The effect of high pressure processing and thermal superficial pasteurization treatment (SPT) on the formation of polyamines, microorganism inactivation and physicochemical characteristics in vacuum-packaged frankfurters was studied (Ruiz-Capillas et al. 2007a). No changes in the polyamines were detected in the pressurized sample. Both superficial pasteurization and pressurization (400 MPa/10 min/30 °C) caused decreases in the levels of total viable and lactic acid bacteria counts where microbial inactivation was higher in the pressurized samples. Irrespective of the treatments assayed, a significant decrease was observed in hardness and chewiness throughout storage.

Diez et al. (2008) applied different mild preservation methods to *Morcilla de Burgos*, a Spanish blood sausage, consisting of a range of organic acid salts (OAS) and highpressure processing, with the aim of increasing its shelflife. An addition of 3 % potassium lactate and diacetate along with the application of 600 MPa for 10 min increased the shelflife of the product by 15 days. Further, same researchers observed the effectiveness of combined preservation techniques on the shelf life of *Morcilla de Burgos* using organic acid salts, high pressure processing and their combination (Diez et al. 2009). HPP (with or without addition of organic acid salts) was considered the most suitable method for preserving the product, as it does not produce negative changes in sensory attributes. No clear selective effect of different treatments on the composition of the spoilage bacteria was seen and similar spoilage patterns were observed independently of the preservation treatment used.

The effect of high pressure processing (400 MPa for 10 min) and natural antimicrobials (enterocins and lactate–diacetate) on the behaviour of *L. monocytogenes* in sliced cooked ham during refrigerated storage (1 °C and 6 °C) was assessed (Marcos et al. 2008a). The efficiency of the treatments after a cold chain break was evaluated. Lactate–diacetate exerted a bacteriostatic effect against *L. monocytogenes* during the whole storage period of 3 months at 1 °C and 6 °C, even after temperature abuse. The combination of HPP, enterocins and refrigeration at 1 °C was found to be the most effective in reducing pathogen population to final counts of 4 MPN/g after 3 months of storage, even after the cold chain break. The efficiency of combining highpressure processing and active packaging technologies to control *L. monocytogenes* growth during the storage of artificially inoculated cooked ham was assessed (Marcos et al. 2008b). Both antimicrobial packaging and pressurization delayed the growth of the pathogen. However, at 6 °C the combination of antimicrobial packaging and HPP was necessary to achieve a reduction of inoculated levels without recovery during 60 days of storage. Further storage at 6 °C of pressurized

antimicrobial packed cooked ham resulted in *L. monocytogenes* levels below the detection limit (day 90). On the other hand, storage at 1 °C controlled the growth of the pathogen until day 39 in non-pressurized ham, while antimicrobial packaging and storage at 1 °C exerted a bacteriostatic effect for 60 days.

Culture-dependent and culture-independent approaches were used to reveal the microbial diversity and dynamic changes occurring in sliced vacuum-packed cooked ham after high pressure processing (400 MPa or 600 MPa for 10 min at 22 °C) during refrigerated storage over 90 days (Han et al. 2011). The predominant spoilage organisms of cooked ham, such as *L. sakei* and *L. curvatus*, were found to be very sensitive to pressure as they were unable to be detected in HPP samples at any time during refrigerated storage. *Weissella viridescens* and *Lc. mesenteroides* survived HPP at 600 MPa and were responsible for the final spoilage. It was concluded that high pressure processing at 400 or 600 MPa for 10 min at room temperature (22 °C) has a powerful inhibitory effect on the major spoilage bacteria of sliced vacuum-packed cooked ham.

Effects of enterocins A and B and sakacin K, nisin, potassium lactate, and a combination of nisin and lactate incorporated interleavers, against *L. monocytogenes* spiked in sliced, cooked ham was evaluated (Jofré et al. 2007). This was followed by high-pressure processing at 400 MPa. HPP of actively packaged ham slices reduced *Listeria* populations about 4 log cfu/g in all batches containing bacteriocins. At the end of storage, *L. monocytogenes* levels in the bacteriocin-containing batches were the lowest, with counts below 1.51 log cfu/g. In contrast, HPP moderately reduced *L. monocytogenes* counts in the control and lactate batches, with populations gradually increasing to about 6.5 log cfu/g at the end of storage. Later, the effectiveness of the application of interleavers containing enterocins A and B, sakacin K, nisin A, potassium lactate and nisin plus lactate alone or in combination with a 400 MPa high hydrostatic pressure treatment was assessed in sliced cooked ham spiked with *Salmonella* spp. (Jofré et al. 2008a). HHP produced a significant reduction in *Salmonella* counts, but the elimination of the pathogen could only be achieved by combining HHP and nisin-containing interleavers. Thus, antimicrobial packaging, HHP and refrigerated storage appeared as an effective combination of hurdles to obtain value added ready-to-eat products with a safe long-term storage.

The effectiveness of the combination of high pressure processing (600 MPa) with the natural antimicrobials nisin and potassium lactate has been evaluated in sliced cooked ham spiked with 4 log cfu/g of *Salmonella* spp., *L. monocytogenes* and *S. aureus* after 3 months of storage at 1 and 6 °C (Jofré et al. 2008b). In non-HPP sliced cooked ham, the addition of nisin plus lactate inhibited the growth of *L. monocytogenes* during the entire storage period while the refrigerated storage inhibited the growth of *Salmonella spp*. and *S. aureus*. The application of an HPP reduced the levels of *Salmonella*, *L. monocytogenes* and *S. aureus*. The combination of HPP, nisin and refrigeration at 6 °C was found necessary to decrease the levels of *S. aureus* by 2.4 log cfu/g after 3 months of storage. Jofré et al. (2009) further observed that addition of enterocins A and B to low acid fermented raw-sausages spiked with 3 log cfu/g of *Salmonella*, *L. monocytogenes* and *S. aureus* reduced the counts of *L. monocytogenes*, while *Salmonella* was more affected by the endogenous

hurdles associated with the ripening process. The application of a HHP treatment of 400 MPa at the end of ripening produced an immediate reduction in the counts of *Salmonella* but not in *L. monocytogenes* or *S. aureus*. During storage of the low acid sausages (*fuets*) at room temperature and at 7 °C, counts of *Salmonella* and *L. monocytogenes* progressively decreased in all batches although the decrease was faster in the pressurized ones stored at room temperature. None of the treatments could control the levels of *S. aureus*.

The inactivation of different spoilage organisms and surrogate pathogens in a cooked ham model product by high pressure (HP) treatment (100–700 MPa, 5–40 °C, 10 min) was investigated (Vercammen et al. 2011). A 5 log reduction could be achieved at ≥600 MPa at ≥25 °C. Subsequently, the shelflife of packaged sliced product was studied during storage (7 °C) after treatment with 600 MPa (10 °C, 10 min) in combination with caprylic acid and Purasal® as antimicrobials. Without HP treatment, a plate count of 6 log cfu/g was reached after 40 days, both in presence and absence of antimicrobials. HP treatment delayed this initiation of spoilage to 59 days in absence of antimicrobials. However, microbial growth was completely suppressed during at least 84 days in the HP treated products containing either of antimicrobial. HP treatment increased drip loss but had no or little effect on colour and sensorial characteristics. However, the antimicrobials had a negative influence on the flavour and aroma at the concentrations used.

Hereu et al. (2012) investigated the effect of nisin application (biopreservation) combined with high hydrostatic pressure processing on the behavior of *L. monocytogenes* CTC1034 intentionally inoculated onto the surface of ready-to-eat sliced dry-cured ham. The results indicated that HHP, as post-processing listericidal treatment, is more effective (both immediately and long term) than the use of nisin as an antimicrobial measure. However, when both the hurdles combined provided a wider margin of safety in the control of *L. monocytogenes* during the storage of RTE cured meat products. Rodríguez-Calleja et al. (2012) reported the combined effects of high hydrostatic pressure and a commercial liquid antimicrobial edible coating consisting of lactic and acetic acid, sodium diacetate, pectin and water ("articoat-DLP") followed by modified atmosphere packaging on the shelflife of chicken breast fillets. The articoat-DLP-HP-MAP combination was the most efficient in extending the durability of chicken breast fillets, which maintained their sensory and microbiological quality for up to 28 days. For articoat-DLP-MAP and HP-MAP fillets, the storage life was estimated to be 2 weeks while that of the untreated fillets (C-MAP) was estimated to be 1 week. Colour, tenderness and overall acceptability were the best maintained sensory attributes during storage for A-HP-MAP samples.

On the basis of above findings it can be said that intelligent use of different hurdles in various combinations have significant scope in reducing the counts of spoilage and pathogenic microflora. Though there are little limitations with some hurdle technologies as far as sensory characteristics of the products are concerned. Thus application of hurdle technology can be helpful towards the processing and delivery of fresher meat and meat products that are nutritious and safe to consume. Additionally hurdle technology is also of great significance particularly in developing countries where refrigeration facilities and power shedding are the greatest challenge.

10.3 Challenges

No single processing technology is complete and there are always positive and negative attributes with each and every technology. Similar is the case with minimal processing techniques too and all the pros and cons should be kept in the mind while application of these technologies in meat and meat products as well as seafood. The main challenges associated with them can be summarized as under:

- Microbiological safety of *sous vide* processed meat and poultry products has been a matter of apprehension especially the survival and potential growth of psychrotrophic foodborne pathogens and spore-forming organisms including *C. botulinum* that could survive the mild heat treatment and potential germination and outgrowth during storage (Hyytiä-Trees et al. 2000). However, a survey of commercially available *sous vide* products concluded that the health risks associated with these products are quite low as long as very low storage temperatures are maintained (Nissen et al. 2002).
- The application and understanding of infrared heating in food processing is still in its infancy (Krishnamurthy et al. 2008b). Infrared treatment of meat and meat product can affect their colour. Infrared heat-treated turkey samples were slightly darker than the controls after treatments, however refrigerated storage for an hour resulted in no significant difference in colour values (Huang 2004). Infrared also has low penetration power and conductivity in solid foods, so heating may require more time. Thus it can be combined with other techniques like microwave heating to achieve the desired attributes.
- Development of hot and cold spots is sometimes linked with microwave heating that depend on the parameters such as product's geometry, composition, dielectric properties and packaging. This could be controlled by the use of vapour inserted in the oven cavity to distribute the heat and packaging with valves (Lacroix et al. 2000).
- Most of the problems related to ohmic heating are due to the electrical nature of the food treated. Compounds with poor conductivity, especially the fat in meat products, do not generate heat as the same rate than muscle thus creating a cold spot (Shirsat et al. 2004b). Geometry factors such as the size of the meat pieces are also important and limit the use of the technology. Other composition parameters such as the acidity may affect the best working conditions of the electrodes and reduce the efficiency of the system. Therefore product composition has to be adapted to the technology (Zuber 1999). Although ohmic cooking procedures are quite mild, there is a risk of toxicological changes in meat and meat products because of direct contact with the electrodes. The effects of ohmic cooking on quality of meat products should also be verified by examining different types of meat products in a wide range of ohmic cooking conditions (Yildiz-Turp et al. 2013).
- During high pressure processing, temperature of food material increases as a result of physical compression. This temperature increase may have an effect on various characteristics of the product like gelling of food components, stability of proteins, migration of fat, etc. The effectiveness of HPP is greatly influenced by

the physical and mechanical properties of the packaging material. The packaging material must be strong with good sealing property and able to prevent quality deterioration during the application of pressure. The headspace must also be minimized while sealing the package to ensure efficient utilization of package as well as space within the pressure vessel. This also minimizes the time taken to reach the target pressure and avoids bursting of package during pressurization.

- An effect on colour, flavour and lipid oxidation of meat and meat products has been observed when they are exposed to ionizing radiation. Increase in the free fatty acids and TBARS number has been observed in the meat treated with ionizing radiation (Kanatt et al. 2006a). Thus it would be needed to take the preventive measures and incorporate antioxidants to prevent the oxidation process.
- Involvement of large initial capital has been associated with pulsed electric fields processing. Pulsed electric fields configurations are primarily optimized for fluid foods and very limited works have been conducted on meat and seafood and further research may be needed to evaluate various PEF chamber configurations that can provide optimal solid product handling. Attention must be paid to potential safety problems due to the presence of entrapped air bubbles in the food matrix that can cause dielectric breakdown during the treatment.
- Attention should be focused for the use of different frequencies ultrasound with varying parameters such as temperature, treatment time, and acoustic power. The increasing use of high-intensity ultrasound depends largely on the availability of low-cost instrumentation that is proven to have significant advantages over alternative technologies.
- Except nisin, other bacteriocins are still lacking the approval from various agencies and countries to be used in the food system. There is need to undertake comprehensive trials on effects of these bacteriocins on human health before their use as food ingredient. Influence of the food matrixes, industry's apprehension, resistant pathogens and economic issues are also the challenges associated with bacteriocins. Incorporation of some of the natural antimicrobials in meat and meat products has been found to affect taste and flavour thus optimum levels of these ingredients should be standardized.
- Some of the physicochemical and functional characteristics of meat and meat products are compromised while application of hurdle concept. These hurdles should be selected intelligently and be used in an appropriate combination to restore various attributes of the products.
- Above all, these technologies are being innovated for the processing of foods in an optimum condition to develop quality and nutritious food; however acceptability among consumers remains a big task.

10.4 Concluding Remarks

Modern consumers prefer diversified attributes, freshness and nutritional assets of the meat and meat products. They also wish to have a product which is free from microbiological hazards. Scientific communities and meat industries have started to

respond to the demands through development of various innovative technologies which are having minimum adverse effects on product's attributes. These technologies are intended for specific functions in meat system including improvement in process speed, functionality enhancement, destruction of pathogenic and spoilage microorganisms, improvement of shelf life, convenience as well as replacement of chemical ingredients as a means to greener approach etc. All of these functions are not encompassed in a single technology and their appropriate combination can solve most of the problems. We can expect that challenges associated with some these technologies would be sorted out in the near future and greener, fresher, safe and nutritious meat and seafood would be available in the market.

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Chapter 11
Processing, Quality and Safety of Irradiated and High Pressure-Processed Meat and Seafood Products

Cheng-An Hwang and Xuetong Fan

11.1 Introduction

Animal meat and seafood have been staple foods for humans for thousands of years. They provide proteins, fats, and nutrients that are essential for good health. Nowadays, meat and seafood remain a major food group in human diet. Worldwide, the production of meat and seafood increases steadily due to the improved economic condition in many countries. The per capita meat consumption increases in almost every country. For example, the consumption of meat was more than doubled in China from 25.8 kg in 1990 to 52.4 kg in 2002 (FAO 2008). The consumption of fish has also increased steadily in the past four decades. The world per capita fish consumption increased from an average of 9.9 kg in the 1960s to 11.5 kg in the 1970s, 12.5 kg in the 1980s, 14.4 kg in the 1990s, and 16.4 kg in 2005 (FAO 2009). With the continuing economic development in many countries, the consumption of meat and seafood products is expected to increase dramatically in the future. In addition to raw meat and seafood, the producers have significantly increased the production of processed meat and seafood products. Traditional processing methods such as chilling, freezing, canning, drying, salting, curing, smoking, fermentation, and cooking have long been used for processing meat and seafood for their preservation. New processing techniques have been developed to process meat and seafood products to meet the demand for variety and high quality products. One of the most adopted approaches is to use less processing intensity to give the products a high organoleptic and microbiological qualities, i.e., minimal processing techniques not only maintains the shelf life and safety of the products but also gives higher sensory quality and nutritional value. These new processing techniques mainly include

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irradiation, high pressure processing, pulsed electric field, and ultra violet and pulsed light radiations. The processing methods of the traditional techniques and their effects on microbiological and sensory qualities have been detailed in publications, such as ICMSF (2005) and Feiner (2006). This chapter summarizes the processing and effects of irradiation and high pressure processing, the two most researched and widely used minimally processing techniques, on the physical, chemical, sensory, and microbiological qualities of meat and seafood products.

11.2 Irradiation

Food irradiation is a non-thermal processing technology that employs electromagnetic radiation to treat food in order to achieve targeted benefits. There are three common types of ionizing radiation that are used on food: gamma rays, x-rays, and electron beam. Gamma rays are emitted from radio-isotopes such as Cobalt-60 and cesium-137. Electron beams are produced by a particle accelerator such as a linear accelerator or Van de Graaff accelerator. X-rays are produced by bombardment of a metal plate with the high power electron beam. Each type of ionizing irradiation has its own advantages and disadvantages (Fan 2012).

11.2.1 Meat and Meat Products

11.2.1.1 Sensory Quality

There were many studies on the effect of irradiation on sensory property of ground beef. Luchsinger et al. (1997) demonstrated that irradiation (2.0 and 3.5 kGy) of frozen ground beef had minimal effect on flavor, texture, or aroma of frozen, raw, and precooked ground beef patties when evaluated by a trained panel. Murano et al. (1998) found that packaging type and storage affected sensory attributes of irradiated ground beef, but no undesirable change was caused by low dose (up to 2 kGy) irradiation. Ground beef patties irradiated under vacuum and stored in air were more tender than the non-irradiated samples. Wheeler et al. (1999) found that irradiated (3 and 4.5 kGy) ground beef was rated by a trained panel as having less beef flavor and aroma and more off-flavor. However, the consumer panel found that patties irradiated at 4.5 kGy had lower taste scores than the non-irradiated patties. Lopez-Gonzalez et al. (2000) found that irradiated (2 kGy) fresh ground beef had less beef/brothy flavor than the non-irradiated ones when evaluated by a trained panel. There were no differences in other sensory attributes between irradiated and non-irradiated samples. Giroux et al. (2001) found no significant difference in odor and taste between irradiated (up to 4 kGy) and non-irradiated ground beef patties during 7 days of post-irradiation storage at 4 °C. Lorenzen and Heymann (2003) found that irradiation (1.0 kGy) of frozen ground patties had little effect on overall

liking, tenderness, juiciness and flavor of cooked patties judged by a consumer panel. Vickers and Wang (2002) found that ratings of overall liking, flavor liking and texture liking for irradiated (1.5 kGy) fresh ground beef did not differ from those of the non-irradiated patties. The rating of juiciness was higher in irradiated patties than the non-irradiated ones. Fan et al. (2004a) irradiated ground beef patties at 1.35 and 3 kGy at −18 °C followed by storage at −18 °C for up to 12 months. Results showed that the degree of liking between non-irradiated samples and the two irradiated samples was similar at either 0, 6, or 12 months of storage. From the above studies, it can be concluded that the trained panel, in general, noted that irradiated ground beef had more undesirable sensory properties than non-irradiated ones at higher dose of irradiation. Mattison et al. (1986) found differences in sensory attributes between irradiated and non-irradiated pork loins 2 days after irradiation, but no difference was found when the meat was sampled 7 days after irradiation. Cabeza et al. (2009) found that dry fermented sausages treated with ≤2 kGy had negligible changes in sensory properties (appearance, odor, and taste). Consumer panels did not find difference in sensory attributes between those irradiated at low doses (less than 3.0 kGy) as compared to non-irradiated ones.

In general, irradiation at low doses does not affect flavor of meats. However, irradiation of meat at high doses may induce a development of an off-odor. The off-odor has been described as rotten egg, bloody, fishy, barbecued corn, burnt, sulfur, metallic, alcohol or acetic acid (Brewer 2009; Ahn and Lee 2012). Evidence indicates that volatile sulfur compounds (VSC) such as dimethyldisulfide and dimethylsulfide (Fan et al. 2002) are mostly responsible for the off-odor due to irradiation (Ahn and Lee 2012; Fan 2004; Fan et al. 2011). The VSCs are mainly formed from sulfur-containing amino acid such as methionine, cysteine, peptides (glutathione and cystine), proteins, or others (thiamine, coenzyme A). To prevent or minimize VSCs and off-odor production of irradiated foods, various additives and packaging types have been investigated. Many researchers suggested various antioxidants to control lipid oxidation and off-odor in irradiated meat (Trindade et al. 2010). Generally antioxidants interrupt autoxidation of lipids either by donating hydrogen atom or quenching free radicals. Fan et al. (2004b) irradiated (up to 3 kGy) bologna made from ground turkey breast containing rosemary extract, sodium erythorbate, or sodium nitrite and showed addition of nitrite, erythorbate, or rosemary extract in raw meat mixtures used for turkey bologna manufacture did not reduce levels of irradiation-induced VSC formation. The antioxidants had strong effects in inhibiting lipid oxidation in irradiated meat.

Irradiation and storage of meat under vacuum-packaging conditions provide some advantages in preventing lipid oxidation. Vacuum-package, however, retained sulfur volatiles produced during irradiation and maintained the levels during subsequent storage (Nam and Ahn 2003a, b). Thus, vacuum-packaged meat produces characteristic irradiation off-odor even after storage. When irradiated meat was irradiated and stored under aerobic conditions, significant amounts of volatile aldehydes (propanal, pentanal, and hexanal) related to lipid oxidation were produced (Nam and Ahn 2003a; Nam et al. 2008). VSCs are highly volatile, and are easily evaporated under aerobic conditions. Therefore, the off-odor caused by irradiation

in meat can be reduced by incorporation of antioxidants for lipid oxidation control and post-irradiation storage to allow flavor to return to near-normal levels via re-packaging or double packaging in oxygen permeable film (Nam and Ahn 2003b).

The color changes in irradiated meat differ significantly depending on various factors such as irradiation dose, animal species, muscle type, and packaging type (Shahidi et al. 1991; Luchsinger et al. 1996; Nanke et al. 1998, 1999; Ahn and Lee 2012). Increased redness is a problem in irradiated white (light) meats and gray discoloration is a problem in irradiated raw red meat under aerobic conditions. Irradiation of meat under vacuum conditions or addition of ascorbic acid to aerobically packaged meat can prevent brown color development in ground beef. Ascorbate also significantly slowed down the development of lipid oxidation in ground beef with double-packaging (aerobically packaged then vacuum packaged) during storage. Therefore, double-packaging in combination with ascorbate can be a good strategy to prevent overall quality changes in irradiated ground beef (Nam and Ahn 2003c).

11.2.1.2 Nutrients and Undesirable Compounds

Dietary intake of *trans* fatty acids has been associated with coronary heart disease. Brito et al. (2002) found that the *trans* fatty acid content of ground beef increased as radiation dose increased. The *trans* fatty acid content increased from 4.6 % (of total fatty acid) for the non-irradiated sample to 8.0 % for 1 kGy sample. Yilmaz and Gecgel (2007) also found significant increases in *trans* fatty acid content of ground beef at doses of 3 kGy or above. Fan and Kays (2009) demonstrated that ground beef and frankfurters irradiated at 5 kGy had slightly higher *trans* fatty acid than the non-irradiated samples. The C18:1 *trans* fatty acid increased from 3.99 % for the non-irradiated ground beef to 4.05 % for the 5 kGy sample, and from 1.21 % for the non-irradiated frankfurter to 1.28 % for the 5 kGy sample. There are natural variations in *trans* fatty acid content. For example, *trans* fatty acid content varied considerably in beef samples obtained from different countries ranging from 2.8 % to 9.5 % of total fatty acid (Aro et al. 1998). Taking the variations in *trans* fatty acid content in meats due to season, feed, age of animal, and storage into account, the effect of irradiation on fatty acid composition at the low doses was minimal.

The radiation sensitivity of vitamins in foods is important from nutritional point of view. Vitamins can be divided into two groups: fat soluble and water soluble vitamins. Meat is a great source of water soluble vitamins from B complex. These vitamins include thiamin (B1), riboflavin (B2), niacin (B5), pyridoxine (B6), biotin (B10), cobalamin (B12), choline, folic acid and pantothenic acid. Radio-sensitivities of different vitamins vary. Vitamin E is the most radio-sensitive among fat soluble vitamins while Vitamin B1 is the most sensitive water soluble vitamin.

The loss of vitamins due to irradiation depends on the nature and composition of the food. In addition, the content of many vitamins often decreases during storage, and degradation of vitamins is also induced by thermal processing or cooking. Furthermore, many environmental factors affect the stability of vitamins. For example, oxygen and temperature during irradiation and post-irradiation storage must be

considered when studying the degradation of vitamins. Fox et al. (1995) and Lakritz et al. (1995) studied the loss of thiamine, riboflavin and α-tocopherol due to gamma irradiation of beef, lamb and pork *longissimus dorsi*, turkey breast and leg muscles. Thiamine losses averaged 11 % per kGy and riboflavin losses were 2.5 % per kGy above 3.0 kGy. Irradiation resulted in a significant decrease in α-tocopherol levels in all of the meats studied. The rate of loss of α-tocopherol in turkey breast tissue was greater than the other meats (Lakritz et al. 1995).

Furan is listed as a possible human carcinogen by the Department of Health and Human Services Report on Carcinogens (NTP 2011) and the International Agency for Research on Cancer (IARC 1995). Furan was present in many thermally processed foods such as soups and meat products that underwent a retort process. The precursors of furan are sugars, ascorbic acid and/or fatty acids (Moro et al. 2012). Fan and Sommers (2006) investigated the generation of irradiation-induced furan in aqueous solutions of some ingredients used in the manufacture of ready-to-eat (RTE) meat products, and in eight RTE meat food products. Irradiation at doses up to 4.5 kGy induced formation of furan in aqueous solutions of sodium-ascorbate, sodium-erythorbate, glucose, honey, and corn syrup. Addition of Na-nitrite into these solutions prior to irradiation completely eliminated, or significantly reduced, furan formation. Most of the non-irradiated RTE products purchased from local markets contained less than 1 ng/g of furan, except for beef and turkey frankfurters which contained 6–8 ng/g furan. Exposure of RTE food products to 4.5 kGy radiation in the non-frozen state (5 °C) or to 10 kGy radiation in the frozen state (−18 °C) did not significantly increase furan levels in frankfurters. Irradiation treatments reduced furan levels in frankfurters that contained more than 3 ng/g of furan. Therefore, irradiation induces furan formation in solutions of many RTE food ingredients, but not in RTE meat and poultry products.

11.2.1.3 Microbiological Quality

Irradiation is an effective method to kill enteric pathogens associated with meat. The populations of most common enteric pathogens such as *Campylobacter jejuni, Escherichia coli* O157:H7, *Staphylococcus aureus, Salmonella* spp., and *Listeria monocytogenes* can be significantly decreased or eliminated by low-dose irradiation (<3.0 kGy). However, enteric viruses and endospores of genera *Clostridium* and *Bacillus* are highly resistant to ionizing radiation (Thayer 1995). Beef was the most commonly reported vehicle for foodborne outbreaks of *E. coli* O157:H7 illness in the U.S. from 1982 to 2002, accounting for 41 % of outbreaks (Rangel et al. 2005). In addition, many non-O157 Shiga toxin-producing *Escherichia coli* (STEC) are now recognized as potential human pathogens. *L. monocytogenes* is a ubiquitous bacterium and capable of proliferation in refrigerated temperatures. It is a frequent post-process contaminant of ready-to-eat meat products. A number of food-borne illness outbreaks and recalls have been attributed to *L. monocytogenes* in the U.S. in recent years.

Table 11.1 D_{10} values of selected human pathogens in meat

Microorganism	Meat	D_{10} (kGy)
Campylobacter jejuni	Beef fillet	0.08–0.11
	Ground beef	0.14–0.32
	Ground pork	0.19–0.27
E. coli O157:H7	Ground beef	0.24–0.30
	Ready-to eat sandwich	0.36
Listeria monocytogenes	Minced pork	0.57–0.71
	Ground pork	0.42–0.45
	Ground beef	0.50–0.61
	Roasted beef	0.64
	Pork jerky	0.65
	Ready-to eat sandwich	0.47
Salmonella Anatum	Ground beef	0.67
Salmonella Enteritidis	Ground beef	0.69
Salmonella Panama	Ground beef	0.66
Salmonella Stanley	Ground beef	0.78
Salmonella Typhimurium	Ground beef	0.55–0.67
	Minced pork	0.39–0.92
	Roasted beef	0.42–0.55
	Beef filet	0.37
	Pork jerky	0.39
Salmonella spp.	Ground beef	0.62–0.66
	Ready-to eat sandwich	0.61
Staphylococcus aureus	Ground beef	0.43–0.5
Yersinia enterocolitica	Roasted beef	0.39
	Ready-to eat sandwich	0.54
	Ground beef	0.10–0.21
	Minced pork	0.16–0.20
	Ready-to eat sandwich	0.15

From Farkas (1998), Thayer (1995), Kang et al. (2012), and Sommers and Boyd (2006)

The irradiation D_{10} values (i.e., irradiation dose needed to achieve 1 log or 90 % reduction of population of microorganisms) are listed in Table 11.1. Many factors affect the D_{10} values, including type of meat, temperature of the meat during irradiation, packaging (atmosphere surrounding the meat), dose rate, and others. For example, El-Zawahry and Rowley (1979) showed that the D_{10} values of *Yersinia enterocolitica* in ground beef were 0.20 kGy at 25 °C while D_{10} value was 0.39 kGy when irradiated at −30 °C. Sommers and Niemira (2011) found that D_{10} values for avirulent *Y. pestis* suspended in beef bologna samples were 0.20, 0.22, 0.25, 0.31, 0.35, and 0.37 kGy at temperatures of 5, 0, −5, −10, −15, and −20 °C, respectively, demonstrating that radiation resistance of bacteria increased with decreasing temperature.

Another factor that affects D_{10} values is the addition of antioxidants/antimicrobials in meat and meat products. Kang et al. (2012) found that the D_{10} values for *E. coli, L. monocytogenes*, and *S.* Typhimurium observed in the irradiated pork jerky samples with leek extract were 0.39, 0.34, and 0.32 kGy, while the D_{10} values in those without leek extract were 0.65, 0.65, and 0.39 kGy, respectively. The results showed that irradiation combined with leek extract was effective in reducing pathogens, suggesting that a low dose of irradiation combined with the addition of a natural antimicrobial agent can enhance the microbial safety and shelf-life of pork jerky. Ayari et al. (2012) demonstrated that the radiation treatment in presence of the cinnamaldehyde and sodium phosphate decahydrate increased the radiation sensitivity of *B. cereus* spores by twofold in ground beef. Irradiation of raw beef meat pretreated with cinnamaldehyde produced an inhibition of the growth of *B. cereus* count during refrigerated storage. A synergetic effect between irradiation and nisin has been observed on the inactivation of *L. monocytogenes* inoculated onto meat or RTE meat products (Jin et al. 2009; Mohamed et al. 2011). The combination is potentially effective in eliminating *L. monocytogenes* in meat.

Kundu et al. (2014) found that electron beam (1 kGy) treatment reduced the viability of two groups of non-O157 STEC mixtures by ≤4.5 and ≤3.9 log CFU/g on fresh beef surface while the log reductions of ≤4.0 log CFU/g were observed for *E. coli* O157:H7 cocktails. Sommers et al. (2013) found that D_{10} values for the non-O157:H7 serovars on meat were significantly lower than those for O157:H7. Those results suggested that radiation resistance of non-O157:H7 STEC in meat is similar or lower than that of O157:H7. Therefore the radiation doses used for inactivating *E. coli* O157:H7 in these foods can also be used for the non-O157:H7 STEC.

11.2.2 Seafood and Seafood Products

11.2.2.1 Sensory Quality and Nutrients

Studies on the sensory evaluation of the irradiated fishes are limited. Moini et al. (2009) found that there was a reasonable and good correlation between sensory property (taste) and bacterial populations. No difference in sensory quality was found by a taste panel between non-irradiated smoked salmon and those irradiated at 2 kGy, but a distinct loss in normal cherry red color of the samples irradiated at 4 kGy was noticed (Hammad and El-Mongy 1992). Fish products contain high levels of unsaturated fatty acids which are more sensitive to oxidation than other components (e.g., saturated fatty acids and proteins). Radiolytic products of unsaturated fatty acids can accelerate lipid oxidation which may lead to rancidity. Very high fat fish species and those with intense color such as salmon may undergo changes in color (loss of pinkness) and/or undergo unacceptable lipid oxidation (Andrews and Grodner 2004). The effect of irradiation on lipid oxidation has been studied using the changes in thiobarbiyuric acid (TBA) values. Irradiation (2 and 3 kGy) increased pH and TBA values and decreased the b* values (yellowness) but

had no effect on water holding capacity or texture of catfish fillets (Gawborisut et al. 2012). Irradiation at a higher dose (5 kGy) elevated TBA values of trout and might induce lipid and protein oxidation (Moini et al. 2009). Chouliaraa et al. (2005) found that TBA values for irradiated, salted sea bream samples were higher than respective non-irradiated (salted) fish, and increased slowly until day 28 of storage reaching final values of 1.01 (non-irradiated, salted), 2.15 (1 kGy) and 3.26 mg malonaldehyde per kg flesh (3 kGy).

Sinanoglou et al. (2007) found that total fatty acid content was not significantly affected by irradiation at doses up to 4.7 kGy in octopus mantle and in shrimp muscle samples. However, a dose-dependent significant decrease in the ratio of polyunsaturated fatty acids: saturated fatty acids was observed. With the increase in radiation dose, color changes increased. Significant changes in textural properties were observed with radiation treatment in octopus tentacles and in squid and cuttlefish mantle. The amount of tropomyosin, which is the major mollusc and crustacean allergen in the irradiated organisms, was reduced by gamma radiation, depending on the dose.

Similar to the effect of vitamins on meat, tocopherol and thiamine are among the most sensitive vitamins to irradiation in fish. For example, effects of gamma radiation dose and irradiation temperature on thiamine, riboflavin and niacin contents were studied in shrimp (*Penaeus monodon*) (Lee and Hau 1996). Thiamine loss increased with increasing irradiation doses and temperature, however, non-significant changes were observed in levels of riboflavin and niacin. In samples irradiated at 7.0 kGy and 4.0 kGy at −20 °C, thiamine losses were 31 % and 23 %, respectively. Vitamin destruction was significantly smaller at −20 °C, in comparison to 4 °C (Lee and Hau 1996).

11.2.2.2 Microbiological Quality

Common pathogens found on fishes include *Salmonella* spp., *Staphylococcus aureus*, *Clostridium botulinum*, *Bacillus cereus*, *Campylobacter jejuni*, *E. coli* O157:H7, *Vibrio parahaemolyticus*, and *L. monocytogenes*. The D_{10} values of some pathogens on fish are shown in Table 11.2. Gawborisut et al. (2012) showed that low-dose irradiation (2–3 kGy) eliminated all *L. monocytogenes* (4.8 log CFU/g) and *S.* Typhimurium (4.7 log CFU/g) on catfish fillets. Ahmed et al. (1997) found that 3 kGy irradiation eliminated the naturally occurring *Salmonella* spp. on Nagli fish (*Sillago sihama*) whereas 2 kGy irradiation destroyed *V. parahaemolyticus* and *S. aureus*. Song et al. (2009b) determined the efficacy of gamma and electron beam irradiation of *L. monocytogenes*, *S. aureus*, and *V. parahaemolyticus* in salted, seasoned, and fermented short-necked clam, and found that gamma irradiation was more effective than electron beam irradiation, and yielded D_{10} values of 0.64, 0.63, and 0.29 kGy for *L. monocytogenes*, *S. aureus*, and *V. parahaemolyticus*, and those of electron beam irradiation were 0.79, 0.81, and 0.36 kGy, respectively. The D_{10} values (gamma irradiation) of 0.60, 0.71, and 0.29 kGy were for *L. monocytogenes*, *S. aureus*, and *V. parahaemolyticus*, and those of electron beam irradiation were 0.69, 0.94, and 0.29 kGy, respectively, were observed in salted, seasoned, and

Table 11.2 D_{10} values of human pathogens in fish

Microorganism	Fish	D value (kGy)	Reference
Bacillus cereus	Kwamegi (semidried raw Pacific saury)	0.64	Chawla et al. (2003)
Bacillus cereus (vegetative cells)	Fish homogenate	0.15–0.25	Kamat and Thomas (1998)
E. coli	Kwamegi (semidried raw Pacific saury)	0.55	Chawla et al. (2003)
L. monocytogenes	Cat fish	0.54–0.67 (thawed)	Rajkowski (2008)
		0.58–0.85 (frozen)	
L. monocytogenes	Tilapia	0.48–0.71 (thawed)	Rajkowski (2008)
		0.54–0.75	
L. monocytogenes	Swordfish	0.51 (frozen)	Sommers and Rajkowski (2011)
L. monocytogenes	Fish homogenate	0.2–0.3	Kamat and Thomas (1998)
Salmonella spp.	Swordfish	0.61 (frozen)	Sommers and Rajkowski (2011)
Salmonella spp.	Fish meal	0.31	Al-Masri and Al-Bachir (2007)
Salmonella Typhimurium	Fish homogenate	0.1–0.15	Kamat and Thomas (1998)
Salmonella Typhimurium	Kwamegi (semidried raw Pacific saury)	0.56	Chawla et al. (2003)
Staphylococcus aureus	Kwamegi (semidried raw Pacific saury)	0.59	Chawla et al. (2003)
Staphylococcus aureus	Swordfish	0.55 (frozen)	Sommers and Rajkowski (2011)
Staphylococcus aureus	Surimi	0.34	Jaczynski and Park (2004)
Yersinia enterocolitica	Fish homogenate	0.09–0.1	Kamat and Thomas (1998)

fermented oyster (Song et al. 2009a). The D_{10} values of *Salmonella* Weltevreden, *V. parahaemolyticus*, and *V. vulnificus* in oyster homogenate were 0.330, 0.159, and 0.140 kGy, respectively (Thupila et al. 2011). Mahmoud (2009) evaluated the inactivation effect of X-ray treatments on *E. coli* O157: H7, *S. enterica*, *Shigella flexneri*, and *V. parahaemolyticus* artificially inoculated in RTE shrimp. Results showed that more than 6 log reductions of *E. coli* O157: H7, *S. enterica*, *S. flexneri*, and *V. parahaemolyticus* were achieved with 2.0, 3.0, and 4.0 kGy X-ray, respectively. Fat content of fishes did not affect the radiation sensitivities of *L. monocytogenes*, *S. aureus*, *B. cereus*, and *Salmonella* Typhimurium or their recovery and subsequent growth during post-irradiation storage (Kamat and Thomas 1998, 1999). Robertson et al. (2006) found that radiation doses of 0.5, 1.0, and 1.5 kGy reduced the population of *L. monocytogenes* by 1.1, 1.6, and 2.1 log CFU/g, respectively. The 2.0-kGy dose reduce *L. monocytogenes* to undetectable levels with no recovery or growth during storage at 3 or 20 °C.

Table 11.3 Shelf-life of selected fish items as affected by low dose irradiation

Fish item	Radiation dose (kGy)	Temperature (°C)	Non-irradiated shelf-life (days)	Irradiated shelf life (days)
Carp	5.0	0–2	15	35
Salmon	1.5	2.2	3–4	20
Trout	1.5	0–2	14–17	28
White fish	1.5–3.0	0	12–15	15–29
Yellow perch	3	0.6	10–12	40–45
Atlantic mackerel	2.5	0.6	8–10	30
Atlantic halibut steaks	3.0	0	6–8	30
Bombay duck	1–2	0–1	7	25
Butterfish	1.2–2.3	0	12	49
Channel catfish	1–2	0	8	20
California halibut	2.0	0.6	7	21–28
Cod fillets	1.5	0.6	7–9	28–35
Flounder, blackback	4.5	0	10	22
Handock fillits	1.5–2.5	0.6	12	18
Halibut	2.5	0	10–12	30
Mackerel, India	1.5	0–2	12	25
Ocean perch fillets	1.5–2.5	0.6	12–14	28
White pomfret	1–2	0–1	10	35
Ribbon fish	1.0	1.0	8	28
Sole (grey) fillet	1–2	0–2	10	29
Sole (English) fillet	2–3	0.6	4–6	28–35
Black pomfret	1–2	0–1	10	25

Adopted from Venugopal et al. (1999)

Many researchers have demonstrated that low dose irradiation (1–3 kGy) extended shelf-life of fishes due to inactivation spoilage microorganisms such as *Proteus morganii* (an organism capable of producing histamine from histidine) and *Pseudomonas* spp. In general, the shelf life of fish can be extended by 2–3 times (Table 11.3) and shelf-life extension depends on many factors including type of fish, initial quality and microbial population of fishes, irradiation dose, and post-irradiation storage conditions such as temperature and packaging. Irradiation has similar effects (as on finfish) on the shelf-life of shellfishes such as clams, shrimps, oysters and lobsters (Farkas 1998). Jeevanandam et al. (2001) dipped fresh, eviscerated threadfin bream in 10 % (w/w) sodium chloride for 1 h and packaged it in polyethylene bags followed by gamma irradiation at doses up to 2 kGy and storage at ice temperature. The unsalted and non-irradiated fish was acceptable up to 8 days in comparison to a storage life of 12 and 22 days for the unsalted fish irradiated at 1 and 2 kGy, respectively. The results suggested that while irradiation could significantly extend the refrigerated shelf life of threadfin bream, and salting prior to irradiation could enhance the acceptability of the irradiated fish. Chouliaraa et al. (2005) stated that a shelf-life of 27–28 days was obtained for vacuum-packaged, salted sea

bream irradiated at 1 or 3 kGy, compared to a shelf-life of 14–15 days for the non-irradiated, salted sample. Moini et al. (2009) studied the effect of gamma radiation (0, 1, 3, and 5 kGy) on the shelf life and bacterial populations of farmed rainbow trout (*Oncorhynchus mykiss*) fillets that were treated with sodium acetate and vacuum packaged. Initial total viable counts of the control samples were ca. 4.4 log CFU/g, whereas the respective counts in samples irradiated at 1, 3, and 5 kGy were 3.1, 1.5, and ≤1 log CFU/g at day 1 of refrigerated storage. The maximum count of *Enterobacteriaceae* reached 2.3 and 1.5 log CFU/g at the end of storage for 1 and 3 kGy, respectively, but at a 5 kGy dose no growth of *Enterobacteriaceae* was observed. Therefore, radiation at a low dose (3 kGy) could be used to control the microbial growth and possible lipid oxidation of trout for up to 4 weeks at refrigeration temperature without adverse effects on quality and acceptability. Treatment with 0.75 kGy X-ray significantly reduced the initial microflora on RTE shrimp samples from 3.8 ± 0.2 log CFU/g to less than 1.0 log CFU/g (Mahmoud 2009).

In general, low dose irradiation (2–3 kGy) can inactivate common pathogenic bacteria (vegetative cells) by at least 4–5 logs CFU/g. In low temperature (frozen) or in the dried state, the bacteria are more resistant (Table 11.2). Viruses in general and spores are much more tolerant to irradiation than pathogenic microorganisms. For example, the D_{10} values of poliovirus (a surrogate of norovirus) in virus culture broth and oyster were determined to be 2.84 and 2.94 kGy, respectively (Jung et al. 2009). There are two major benefits of using low dose ionizing radiation as a processing technology for fishes and fish products. First, it reduces or eliminates the population of microorganisms responsible for spoilage and subsequently extend shelf-life of the products. Second, the same low dose radiation can reduce or eliminate pathogenic bacteria commonly associated with fish products (Andrews and Grodner 2004).

11.3 High Pressure Processing

High pressure processing (HPP), also known as high hydrostatic pressure (HHP) or ultra high pressure (UHP) processing, uses hydrostatic pressures commonly between 100 and 800 MPa at temperatures of <0–100 °C to treat food products. The extreme high pressure inactivates microorganisms in the foods, therefore gives the desired shelf life to the products (Simonin et al. 2012). The microbial inactivation is due to pressure-induced damages to the cell membranes, cell wall, and cellular functionality that adversely alter the cell permeability, transport systems, osmotic regulation, and intracellular pH (Ritz et al. 2001; Park et al. 2001; Kato et al. 2002). The levels of microbial inactivation in foods achieved by HPP depend on the type of microorganism, its growth phase, the pressure levels, time, and temperature, and the foods' composition, pH, and water activity (Tewari et al. 1999). In general, the inactivation rates are higher at higher pressures, Gram-negative bacteria are most sensitive to pressure than Gram-positive bacteria, cells in the exponential growth phase are more sensitive to pressure than those in the stationary phase, and bacteria are more

resistant to pressure inactivation at their optimal growth temperatures (Escriu and Mor-Mur 2009; Campus 2010). Like responding to other environmental stresses, bacteria are able to develop resistance to high pressure. Vanlint et al. (2012) reported that, among strains of *Escherichia coli*, *Shigella flexneri*, *Salmonella enterica* serovars Typhimurium and Enteritidis, *Yersinia enterocolitica*, *Aeromonas hydrophila*, *Pseudomonas aeruginosa*, and *Listeria innocua* tested, some *E. coli* strains were able to acquire a stable HPP resistant trait that lasted for >80 generations. HPP has also been studied for potential to inactivate foodborne viruses such as hepatitis A virus (Kingsley et al. 2002, 2006; Grove et al. 2009), human norovirus (Li et al. 2013), and enteric viruses (Hirneisen and Kniel 2013). The high pressure appears to denature capsid proteins in the virus which render the virus incapable of binding to the host cells (Kingsley 2013).

The initial development of HPP focused on pasteurization application that aimed at inactivating vegetative bacterial cells. As the technology advances, research are expanding to examine the use of high pressure and higher temperatures for sterilization application in producing low-acid canned foods which are currently produced mostly by heat processing. The inactivation of bacterial spores by high pressure requires the application of higher temperatures (mostly >100 °C) than those used for inactivating vegetative bacterial cells (Peleg et al. 2012). Studies have been conducted to examined pressure-assisted sterilization on proteolytic types A and B strains of *Clostridium botulinum* (Reddy et al. 2013; Patazca et al. 2013), *Bacillus subtilis*, *B. amyloliquefaciens*, and *B. licheniformis* (Margosch et al. 2004; Rajan et al. 2006; Ratphitagsanti et al. 2009), and *C. botulinum* and *B. amyloliquefaciens* (Margosch et al. 2006). For example, Ahn et al. (2007) reported that a treatment of 700 MPa at 121 °C for 1 min inactivated 7–8 log spores of *C. sporogenes*, *C. tyrobutylicum*, *Thermoanaerobacterium thermosaccharolyticum*, *B. amyloliquefaciens*, and *B. sphaericus*. The increased sensitivity of bacterial spores to heat under high pressure is linked to the release of Ca^{+2}-dipicolinic acid in the spores (Reineke et al. 2011).

Depending on the composition of the foods, the high pressure during HPP increases the food temperature approximately 3 °C/100 MPa. The heat and pressure used in HPP generally have no significant effect on the food's flavor components, nutrients, and chemical reactions. There has been no evidence that chemical reactions in foods at high pressure and temperatures, e.g., those for pressure-assisted sterilization, would produce toxin compounds (Bravo et al. 2012). It would be expected that furan be produced at high temperatures during HPP from aqueous solutions of ascorbic acid, simple sugars and fatty acids although the levels of furan formation will probably be lower due to lower temperature employed for HPP sterilization compared to the thermal conditions without high pressure. Numerous studies have been conducted to identify the HPP parameters (treatment pressure, temperature, and time and food factors) for specific food products that deliver the maximum microbiological and sensory quality. The reported HPP parameters and effects for selected food products have been summarized by Campus (2010), Bajovic et al. (2012), and Simonin et al. (2012). In addition, mathematical models that describe the effects of HPP parameters on microbial inactivation have also been

developed (Doona et al. 2005, 2012; Tananuwong et al. 2012). HPP is a processing technique that is capable of producing safe and high sensory and nutritional foods. The technology has been widely used in processing meat and seafood products in the U.S., Japan, and European countries. This section reviews the effects of HPP on the physical, chemical, and microbiology quality of meat and seafood products.

11.3.1 Meat and Meat Products

11.3.1.1 Water Holding Capacity, Tenderness, and Cooked Yield

Water-holding capacity, cooked yield, and tenderness are important factors for meat and meat products for assessing its quality. In general, HPP increases water-holding capacity, cooked yield, and tenderness of meat and meat products. The pressure in HPP creates protein hydration and causes raw protein to unfold and exposes non-covalent interactions that lead to improved yield and moistness and reduced liquid loss of meat and meat products. Mor-Mur and Yuste (2003) observed that sausages treated with 500 MPa at 65 °C had less weight loss as compared to heat-treated sausages after cooking. Schenkova et al. (2007) reported that a brief exposure of cow muscle to 100 and 300 MPa at 10 °C decreased the hardness of the muscle. HPP (100–400 MPa, 10–20 °C) and salt (1–2 %) reduced the cooking loss of meat batters (Iwasaki et al. 2006; Sikes et al. 2009). Bowker et al. (2010a) examined the effects of HPP on marination and meat quality characteristics of turkey breasts and found that HPP increased brine uptake and processing yield and reduced cooking loss and hardness. In another study, Bowker et al. (2010b) observed a similar result for moisture-enhanced pork loins. Souza et al. (2011) examined HPP (215 MPa, 33 °C, 15 s) on postmortem metabolism and pork quality and found that HPP partially inhibited postmortem metabolism and increased cook yield and tenderness. An increased water-holding capacity induced by HPP was also observed in frankfurters (Souza et al. 2012). A tender meat was obtained when post-rigor meat was treated at 100–200 MPa while the temperature was raised from ambient to around 60 °C (Ma and Ledward 2013). The effect of HPP on the water-binding capacity of salt-soluble meat protein containing 0.2 % $CaCl_2$ and 0.6 % k-carrageenan gels was investigated by Ma et al. (2013). The results showed that 300–400 MPa improved the water-binding capacity and suggested that HPP might be used to produce low-fat and low-sodium meat products. Raw ostrich sausages treated with HPP (300–700 MPa, 40–60 °C) had been shown to increase gel strength and water-holding capacity (Chattong and Apichartsrangkoon 2009). The effect of pressure to increase the solubilization of proteins, emulsification of fat, and forming of a stable gel network in meat are part of the factors that contribute to the water holding capacity of meat and meat products (Iwasaki et al. 2006; Sikes et al. 2009). Beef samples pressurized at 200, 300, and 400 MPa at two different temperatures at 20 °C and 40 °C showed pressure and temperature had significant effects on cooking losses and lower pressure (200 MPa) at 40 °C had a lower cooking loss than at higher pressure

(McArdle et al. 2010). High pressure results in different water retention capacity and texture, depending on the product's form and composition and the pressure level, temperature, and time. Combining high pressure and heat can improve the water holding capacity, texture, and meat binding in meat and meat products, however, each product needs to be tested for the optimal pressure level, temperature, and treatment time.

The tenderization of meat is caused by the weakening of muscle and connective tissues, fragmentation of myofibrils, and degradation of elastic filaments (Koohmaraie 1994) by pressure, protease, and enzymes such as cathepsins and calpains (Kubo et al. 2002). An increased protease and enzymatic activities, the loss of collagen toughness (Ma and Ledward 2004; Sikes et al. 2010), and the weakening of muscular connective tissue (Ichinoseki et al. 2006) under pressure have been attributed to the improved tenderness of raw meat. High pressure tenderizes and softens or restructures meat, and subsequently affects the texture and gel-forming properties of myofibrillar proteins in meat products. The rate and magnitude of how pressure and temperature affect the texture, microstructure, and gelation of myofibrillar proteins that influence the tenderness of meat are varied and depend on a number of factors that are still not well understood (Buckow et al. 2013).

11.3.1.2 Lipid Oxidation

Meat and meat products, particularly chicken meats, contain high amounts of fat and are susceptible to lipid oxidation. The oxidation leads to rancidity and off-flavors which are a major cause of quality deterioration of these products during storage. Therefore, the effects of HPP on lipid oxidation have been studied extensively and reported to be varied among meat types, composition, mechanical processing before HPP treatment, and treatment pressure, temperatures, and time (Beltran et al. 2003; McArdle et al. 2010; Clariana et al. 2012; Fuentes et al. 2010; Wang et al. 2013; Kang et al. 2013). Generally, higher pressure and temperatures and longer treatment times increase the rate of lipid oxidation. In addition, the unsaturated lipids in the meat become more susceptible to oxidation at pressures >400 MPa, possibly due to the release of iron in meat and/or damage in the lipid membrane (McArdle et al. 2010). High lipid oxidation as indicated by the values of thiobarbituric acid reactive substances was observed in pressure-treated minced meat (Cheah and Ledward 1996), chicken breast (Orlien et al. 2000), and turkey meat (Tuboly et al. 2003). Orlien et al. (2000) reported that vacuum-packaged chicken breast muscle treated with 300–800 MPa at 25 °C for 5–10 min developed lipid oxidation with >600 MPa pressure and the highest level of lipid with 800 MPa for 10 min. Studies showed an increased lipid oxidation during storage of pressure-treated minced chicken (500 MPa, 50 °C, 30 min), dry cured ham (600 MPa, 12 °C, 6 min), beef (200–300 MPa, 20 and 40 °C), and ready-to-eat meat products (Orlien et al. 2000; Beltran et al. 2003, 2004a; Fuentes et al. 2010; McArdle et al. 2010). Tuboly et al. (2003) also reported an increased lipid oxidation after HPP (400 MPa for 20 min) and after 4 and 8 months of frozen storage.

The increased lipid oxidation by HPP has been attributed to the rupture of adipocytes in meat (Carballo et al. 1997), reduced antioxidant enzyme activity (Serra et al. 2007), the release of iron from complexes present in meat (McArdle et al. 2010), and the formation of free radicals induced by high pressure (Bolumar et al. 2014). An increased formation of radicals was observed with increased pressures, temperatures above 25 °C at 400 MPa and above 5 °C at 500 MPa (Bolumar et al. 2012). Packaging the meat products in vacuum packages or modified atmosphere packages prior to pressurization (Andres et al. 2006; Campus et al. 2008) and the adding of chelating agents and antioxidants, such as EDTA and egg white powder (Beltran et al. 2004b), could reduce the pressure-induced lipid oxidation.

11.3.1.3 Color and Aroma

Bright red color is perceived as an indication of freshness of raw meat. When subjected to certain high pressures at ambient temperature, meat and meat products undergo color changes. Many studies have reported that high pressure influences the color of raw meat. Cheah and Ledward (1996) reported that meat color was more stable at lower pressure levels (80–100 MPa). McArdle et al. (2010) examined raw beef treated at 200–400 MPa at 20 °C and 40 °C and reported that lower pressure levels had less impact on color changes and the change of color was due to the denature of actomyosin at about 200 MPa and the denature of myoglobin or precipitation of proteins at about 400 MPa. Beltran et al. (2004a), Del Olmo et al. (2010), and Marcos et al. (2010) all observed an increase in lightness (L^*) of raw meat color at pressures above 200 MPa. The increases in lightness were observed in beef treated with 200–600 MPa (Carlez et al. 1995; Marcos et al. 2010), in pork treated with 200–400 MPa (Korzeniowski et al. 1999), and in chicken meat treated with 400–500 MPa (Beltran et al. 2004a; Del Olmo et al. 2010). The increase in lightness of meat under pressure has been attributed to protein coagulation (Goutefongea et al. 1995), denature of myoglobin, heme group displacement or release, and/or the oxidation of the ferrous myoglobin to ferric myoglobin (Carlez et al. 1995). In raw beef, a significant effect of high pressure on the a^* value (redness) was also reported. Jung et al. (2003) performed pressure treatments (50–600 MPa, 10 °C, 5 min) on raw beef muscle and reported that an increase in pressure up to approximately 350 MPa led to an increase in a^* values and that these values decreased at pressures up to 600 MPa. They attributed the increase in a^* values at pressures below 300 MPa to the possible activation of the enzymatic system responsible for metmyoglobin reduction. The extents of color alteration due to high-pressure treatment in beef patties (Carballo et al. 1997) and in pork sausages (Jimenez-Colmenero et al. 1997) have been shown to be influenced by the fat contents. High fat contents (20–25 %) were associated with greater color changes, particularly lightness. The color of cured products is less affected by pressure than the color of raw meat (Karlowski et al. 2002; Rubio et al. 2007). While the color of raw meat appears to be affected by the pressure, the color of cured meat did not seem to be affected by pressure. Bak et al. (2012) examined the color changes of minced cured hams of various pH and

salt contents treated with 600 MPa at 13 °C for 5 min, and concluded that the pressure treatment did not change the pigment responsible for the color of the cured ham. High pressure treatments altered the aroma profiles of raw and processed meat products. Schindler et al. (2010) reported that the aroma profiles of raw chicken and beef treated with HPP of 400–600 MPa at 5 °C for 15 min were not significantly altered during a 14-day chilled storage in comparison with untreated meat. Rivas-Canedo et al. (2009) showed that the volatile profiles of cooked pork meat treated with 400–600 MPa at 12 °C for 5–10 min were not altered during refrigerated storage. High pressure treatments at 300–400 MPa at 20 °C for 10 min were shown to reduce the contents of volatile compounds originating from the Maillard reaction in dry-cured loin (Campus et al. 2008) and 100–300 MPa at 25 °C for 10 min increased the overall autolytic activity of raw meat and leads to a higher concentration of free amino acids (Ohmori et al. 1991).

11.3.1.4 Microbiological Quality

Listeria monocytogenes is frequently found in meat processing plants and hence has a potential to cross-contaminate meat products. The pathogen is capable of growing at refrigeration temperatures and causes high fatality in infected patients. Its contamination in meat products is a major food safety concern, particularly for ready-to-eat meats which are often consumed without prior heating. Therefore, the effects of high pressure treatment on the inactivation of *L. monocytogenes* have been extensively studied. Generally, a treatment at 400 MPa is necessary to significantly decrease the *L. monocytogenes* load in meat products (Simpson and Gilmour 1997; Chen 2007). Murano et al. (1999) obtained a 10-$\log_{10}$ reduction of the most resistant strain of *L. monocytogenes* in fresh pork sausage with a HPP treatment of 400 MPa at 50 °C for 6 min. In chicken batters, a 400 MPa–20 °C–2 min treatment reduced 1.5–3 log CFU/g of *L. innocua* (Escriu and Mor-Mur 2009). For processed meat, a HPP treatment of 600 MPa for 9 min reduced 5 log CFU/g *L. monocytogenes* in dry-cured hams (Tanzi et al. 2004) and a 483 MPa at 18 °C for 5–12 min or 600 MPa at 18 °C for 1–7 min reduced 1.6 to ≥5 log CFU/g *L. monocytogenes* in salami (Porto-Fett et al. 2010). The effect of high-pressure treatment on the survival of inoculated *L. monocytogenes* Scott A in cured ham was examined by Morales et al. (2006). A treatment of 450 MPa at 12 °C for 10 min reduced the *L. monocytogenes* populations by 1.2–1.5 log and the survived population continued to die off during refrigerated storage. Chen (2007) examined a HPP treatment of 300 MPa for 2 min, 400 MPa for 1 min, and 500 MPa for 1 min at initial sample temperatures of 1–55 °C in inactivating *L. monocytogenes* in vacuum-packaged ready-to-eat turkey breast meat. He reported that *L. monocytogenes* was most sensitive to pressure at temperatures <10 and >30 °C and the sensitivity increased at higher temperatures than at lower temperatures. Bover-Cid et al. (2011) developed a polynomial model of the inactivation of *L. monocytogenes* in dry-cured ham at different HPP conditions (347–852 MPa, 7.6–24.4 °C, 2.3–15.75 min). The pressure and time were shown to be the most important factors that determined the inactivation while the temperatures was

not a significant factor. Little inactivation effect was observed at pressures below 450 MPa and holding times longer than 10 min did not result in more reduction of *L. monocytogenes*. Examining the effect of combining pressure and antimicrobials against *L. monocytogenes*, Hereu et al. (2012) reported that the combination of nisin and HPP 600 MPa for 5 min significantly reduced *L. monocytogenes* on the surface of ready-to-eat sliced dry-cured ham, and the reduction was greater in lower a_w products.

HPP treatments (pressure, temperature, and time) that can effectively reduce *L. monocytogenes* in meat and meat products are also generally effective in inactivating *Salmonella* spp. (Garriga et al. 2002; Jofre et al. 2009). A HPP treatment of 600 MPa at 31 °C for 6 min reduced >2.5 log *Salmonella* spp. in cooked ham, dry-cured ham, and marinated beef loin (Jofre et al. 2009), a treatment at 500 MPa at 50 °C for 10 min reduced >7 log *Salmonella* spp. in poultry sausages (Yuste et al. 2000), and treatments of 400, 500 and 600 MPa (5 min, 12 °C) reduced *Salmonella* Enteritidis by 1.1, 2.5, and 4.3 log, respectively, in sliced dry-cured ham (de Alba et al. 2012). For raw meat, Morales et al. (2009) reported that treatments of 300 MPa and 400 MPa (12 °C, 20 min) reduced *Salmonella* by 3.4 log CFU/g and >5 log CFU/g, respectively, in chicken breast, and the numbers of injured *Salmonella* cells increased with the increase of pressure. The survival curves of *Salmonella* spp. under high pressure processing showed a rapid initial drop in *Salmonella* population with a diminishing inactivation rate or tailing effect and were more satisfactorily described by Weibull models than a linear model (Chen 2007; Tananuwong et al. 2012).

Campylobacter jejuni is one of the leading causes of foodborne illnesses linked to the consumption of chicken meat, while *E. coli* O157:H7 is frequently implicated in foodborne illnesses linked to under-cooked beef products. Studies examining HPP on both pathogens have also been conducted and it has been found that both pathogens are fairly sensitive to pressure inactivation. For examples, Martinez-Rodriguez and Mackey (2005) showed that a HPP treatment of 200 MPa at 25 °C for 10 min reduced 2 log CFU/g of *C. jejuni* in chicken meat, and Lori et al. (2007) reported that a treatment of 450 MPa at 15 °C for 30 s reduced >6 log CFU/g *C. jejuni* in chicken slurry. For *E. coli* O157:H7, a 5-log reduction was achieved by treatments of 483 MPa at 19 °C for 5 min in dry-fermented salami (Porto-Fett et al. 2010) and 700 MPa at ambient temperature for 5 min in minced raw minced meat (Gola et al. 2000).

The microbiological shelf life of meat and meat products is generally extended by HPP due to the inactivation of spoilage microorganisms. For example, pressures between 300 and 450 MPa are capable of completely inactivating *Pseudomonas* spp., one of the main spoilage microorganisms in meat products (Carlez et al. 1995; Lopez-Caballero et al. 2002). Garriga et al. (2002) showed that a HPP treatment of 600 MPa at 31 °C for 6 min reduced spoilage microorganisms by 4 log in marinated beef loin, by 2 log in dry-cured ham, and the shelf life of both products was significantly extended. Han et al. (2011) examined HPP treatments of 400–600 MPa at 22 °C for 10 min on the microbial diversity and dynamic changes in sliced vacuum-packaged cooked ham during refrigerated storage. Results showed the pressure

affected the microbial species differently and the predominant spoilage organisms such as *Lactobacillus sakei* and *L. curvatus* were very sensitive to pressure. Among spoilage microorganisms, psychrotrophs are more sensitive to pressure inactivation than mesophiles (Yuste et al. 2001; Garriga et al. 2002).

11.3.2 Seafood and Seafood Products

11.3.2.1 Physical, Chemical, and Sensory Qualities

HPP at pressures between 250 and 500 MPa denatures the specific protein that holds the meat to the shell of shellfish such as lobsters, oysters, crabs, and clams. The denature allows complete separation of the meat from the shell which increases the quantity and quality of meat removed from the shell (He et al. 2002; Murchie et al. 2005). Under high pressures, the protein substrates in uncooked surimi products become more accessible to transglutaminase and result in the formation of a cross-link protein network that increases the gel strength after cooking (Ashie and Lanier 1999). In raw fish treated with pressures above 200 MPa, the toughness and elasticity of the fish muscle decreased as the pressure increased (Ashie and Simpson 1996; Campus et al. 2010). The effects of HPP on the firmness and texture of fish muscle appeared to be pressure dependent. Cheret et al. (2005) evaluated the effect of high pressure on proteolytic enzymes, cathepsins B, D, H, and L and calpain, on the degradation of fish muscle during storage. The authors reported that HPP with pressures >500 MPa increased the activity of cathepsin B, H, and L, while the pressure decreased the activity of calpain and no activity was observed at 400 MPa. Teixeira et al. (2013) also examined the effects of HPP of 100, 250, and 400 MPa at pressurization rates of 8 and 14 MPa/s for 0, 5, 15, and 30 min on sarcoplasmic proteins and the activity of acid phosphatase, cathepsins (B and D), lipase, and calpains in sea bass fillets and reported that an increase in pressure level and holding time decreased the protein concentration in sarcoplasmic extracts and the activity of calpains. By applying HPP, the protein in raw fish or processed fish products can be changed to increase water holding capacity, improve firmness, form desired gel strength, and reduce water loss during storage or cooking.

Similar to meat products, high pressure generally increases lipid oxidation and textural changes in most fish and fish products. When a mix of sardine oil and defatted sardine meat was treated at 100 MPa for 30–60 min, the lipid oxidation during cold storage increased more rapidly in samples treated with longer processing times (Tanaka et al. 1991), and HPP treatments of 200–600 MPa for 15–30 min increased the rates of lipid oxidation in cod muscle (Oshima et al. 1993). When rainbow trout were treated with 150, 300, 450, and 600 MPa for 15 min, the lipid oxidation of the fish during storage increased with prior increased treatment pressure (Yagiz et al. 2007). The effect of pressure on color of fish meat is influenced by fish species. HPP appears to maintain the sensory quality or improve the overall sensory of seafood. A consumer panel that evaluated the sensory quality of littleneck

hard clams (*Mercenaria mercenaria*) treated with 310 MPa for 3 min indicated equal preference for processed and raw samples (Narwankar et al. 2011). Matejkova et al. (2013) examined the effects of vacuum packaging followed by HPP at 300 and 500 MPa on the organoleptic quality of rainbow trout (*Oncorhynchus mykiss*) fillets and reported that samples treated with pressure had better organoleptic quality.

11.3.2.2 Microbiological Quality

Vibrio parahaemolyticus and *V. vulnificus* causes the most cases of foodborne illness linked to the consumption of seafood (Cook 2003). HPP has been shown to be effective in killing both pathogens. HPP at 345 MPa for 7.7 min reduced 4.5 log *V. parahaemolyticus* and 345 MPa for 6 min reduced >5.4 log *V. vulnificus* in oysters (Koo et al. 2006). In a study by Kural and Chen (2008), oyster meats inoculated with a pressure-resistant strain of *V. vulnificus* were treated at 150 MPa for 4 min and 200 MPa for 1 min (temperatures at −2, 1, 5, 10, 20, 30, 40, and 45 °C). The results showed that temperatures at <20 °C and >30 °C substantially increased pressure inactivation of *V. vulnificus*. At treatment temperatures of −2 or 1 °C, pressures at ≥250 MPa for ≤4 min was able to achieve a >5-log reduction of *V. vulnificus* in oysters. In another study to identify HPP conditions (pressure level, time, and temperature) that were needed to achieve a 5-log reduction of *V. parahaemolyticus* in live oysters (*Crassostrea virginica*) inoculated with two pressure-resistant strains of *V. parahaemolyticus*. Results showed treatments at ≥350 MPa for 2 min at 1–35 °C and ≥300 MPa for 2 min at 40 °C were needed to achieve a 5-log reduction of *V. parahaemolyticus* in live oysters (Kural et al. 2008). Mootian et al. (2013) examined the effect of HPP on the survival of *V. parahaemolyticus* in live clams (*Mercanaria mercanaria*). The clams were inoculated with 7 log CFU/g *V. parahaemolyticus* and treated at pressures 250–552 MPa for 2 and 6 min. A >5-log reduction of *V. parahaemolyticus* was achieved by the processing conditions of 450 MPa for 4 min and 350 MPa for 6 min. Studies also showed that HPP at 300 MPa at 21 °C for 2 min, followed by a 5-day ice storage or 7-day frozen storage, and at 250 MPa at 21 °C for 2 min, followed by 10-day ice or 7-day frozen storage, reduced >7 log *V. parahaemolyticus* in whole-shell oysters (Liu et al. 2009; Ye et al. 2013). For inactivating spoilage microorganisms, a pressure of 300 MPa for 15 min reduced 4 and 6 log of the initial microbial population on fillets of rainbow trout and mahi mahi, respectively, and the subsequent growth of the survived microorganisms was delayed (Yagiz et al. 2007). In hard clams (*Mercenaria mercenaria*), pressures at >480 MPa was needed to reduce 1 log of the native microbial population (Narwankar et al. 2011). For inactivating virus, HPP treatments of 600 MPa at 6 and 25 °C completely inactivated Norwalk virus in oysters (Leon et al. 2011), treatments of 500 or 600 MPa and 300 or 400 MPa for 1 min were able to completely inactivate feline calicivirus in clams (Tibollo et al. 2013), and treatments of 300–500 MPa for 1–10 min were effective in inactivating norovirus in manila clams (Arcangeli et al. 2012). Overall, HPP has a high efficacy in inactivating viruses in seafood products.

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Chapter 12
Sustainability and Challenges of Minimally Processed Foods

J.E. Dávila-Aviña, L.Y. Solís-Soto, G. Rojas-Verde, and N.A. Salas

12.1 Introduction

Food safety challenges in recent years have been emphasized by the demand of "minimally processed" products. Minimally processed products have been defined as food products that went through very little processing. Processing affects shelf-life, providing ready-to-eat food with similarities to fresh products (Ohlsson and Bengtsson 2002). The food industry has been urged to utilize novel technologies to produce safe food without detrimental effects on quality. As consumers are demanding high quality minimally processed foods, manufacturers face new challenges to develop safe and nutritious products (Rastogi et al. 2007; Sun-Waterhouse et al. 2014). One of the challenges of high priority is the rapid detection of pathogens in food products. New testing methods need to be standardized and verified prior to their adoption by industry and authorities. Testing methods must have desired sensitivity and accuracy, and these should need rapid results as well as low cost (Alzamora et al. 2012; Ngadi et al. 2012). This chapter focuses on the integration of main factors and challenges of "minimally processed" products. These include a brief description of their globalization process and sustainability as well as consumers' perception.

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12.2 Sustainability and Consumers' Perception

The globalization of the food trade offers many benefits to the consumers and it results in a wide variety of high quality foods. The global food trade provides opportunities for food-exporting countries to earn foreign exchange, which is indispensable for the economic development of many countries (Alpas and Kiymaz 2012). However, the integration and globalization of the foods are changing the food production and distribution patterns. Foods are now distributed over greater distances, thus it is creating the possibility for widespread outbreaks and foodborne illness. Increasing urbanization also leads to greater requirements for transport, storage and food preparation (Fresco 2009). Nowadays, consumers possess higher expectations than ever before. They want their foods to be more nutritious and safe, with adequate variety and longer shelf life (Spence 2006). However, these changes also present new challenges to produce safe foods. The food safety programs are increasingly focusing on a "farm-to-table" approach and it is an effective means of reducing food born hazards. Although significant progress has been made in many countries in making food safer, millions of people get sick each year for eating contaminated food products. The public is increasingly aware of the risks of pathogenic microorganisms and chemical substances in the food supply. Furthermore, ever-increasing consumer interest in dietary supplements offers special challenges to guarantee the safety of food products (Akkerman et al. 2010). Finally, unexpected contamination of food and cosmetics, whether by familiar or previously unrecognized agents, will continue to occur despite of new emphases on their prevention (Barbosa-Cánovas et al. 2003; FDA 2013).

The demand of minimally processed foods have increased in recent years. Today, the consumers are more health conscious and they are interested on healthy foods. This means low thermal treatment without additives and/or artificial flavors (Moses et al. 2014). Unfortunately, in some instances, a treatment can cause changes in chemical composition, physical and biological changes, thus it can reduce their acceptance of products and become susceptible to microbial contamination.

12.2.1 Food Safety

Food safety has become a major food security challenge. It is a well known fact that foodborne microbial hazards are a constant threat across the supply chain. As consumers are demanding high quality minimally processed foods, manufacturers are facing new challenges to develop safe and nutritious products (Moubarac et al. 2014; CSIRO 2012). The approach to control the risks involves the consideration of every step in the chain (i.e. from raw material to final product). Hazards can enter in the food chain during their farming and can be introduced or exacerbated at any point in the chain (Rosegrant and Cline 2003).

In this context, achieving food security continues to be a challenge not only for the developing countries, but also for the developed nations. Food security is affected

by complex factors including unstable social and political environments that preclude sustainable economic growth, natural resource constraints, poor human resource base, poor health, and natural disasters. All these factors contribute to either insufficient national food availability or insufficient access to food by households and individuals (IFPRI 2002).

The progress of industry and food regulators will come in the form of closer vigilance of food safety issues as the global food supply shifts towards fresh and minimally processed products, which may be imported more frequently and in larger quantities. Industry will continue to seek new rapid methods of testing foods and new technologies to identify and to control possible food hazards. Likewise, consumers will push for new technologies in processing and packaging that use innovative approaches to yield foods having a "less processed" quality (Taeymans 2000).

12.3 Challenges in Minimal Processed Foods

Today food preservation is the main key in the global food supply. For this reason, food scientist are focusing on new technologies which can meet the needs of growing consumers. In order to maintain the shelf-life of minimally processed foods, some methods or technologies have been described for retaining their safety, nutritional quality, and sensory characteristics (González-Aguilar et al. 2008). The introduction of new technologies, including genetic engineering, irradiation, application of pulsed electric field (PEF), high-pressure, ultrasound, active packaging and ozone to extend the shelf-life can pose a special challenge in food safety (Ortega-Rivas 2012; Vaclavik and Christian 2014; Heldman 2013; Smith 2011). Some new technologies will increase agricultural production and make food safer, but their usefulness and safety must be demonstrated if they are going to be accepted by consumers (González-Aguilar et al. 2010). Furthermore, the evaluation must be participatory, transparent, and conducted using internationally agreed methods.

In all kind of foods, including minimally processed foods, technical innovations will lead to the production of safer foods that will have new flavors, textures, nutriments, and will be more convenient to prepare and have a longer shelf-life. Furthermore, new processes, packaging materials, equipment, testing procedures and safety systems will also lead to advances in the overall systems for food handling and delivery. Traditional methods for sterilizing and disinfecting food must change to accommodate consumer preference for fresh and minimally processed foods.

12.3.1 Use of New Technologies and Treatments

12.3.1.1 Packaging

To keep the minimally processed foods quality, several technologies, such as the use of modified atmosphere packaging (MAP) or reduced oxygen-controlled atmosphere (CA), have been introduced. Packaging provides protection of foods from

Table 12.1 Examples of active packaging and the additives used

Type of AP	Additive	Effect	Application	Reference
Edible packaging of chitosan		Antimicrobial activity against pathogenic and spoilage fungi, Gram-positive and Gram-negative bacteria	Films, coating, gels, beads	Dutta et al. (2009)
Coating of Starch-chitosan		Growth inhibition of total coliforms and lactic acid bacteria	Minimally processed carrot	Durango et al. (2006)
Agar-Agar	Chitosan and acetic acid	Growth inhibition of filamentous fungi and aerobic mesophilic	Minimally processed garlic quality	Geraldine et al. (2008)
Chitosan/methyl cellulose		Reduction of number of yeast	Fresh cantaloupe and pineapple	Sangsuwan et al. (2008)
Cellulose	Nisin	Antimicrobial activity agains *S. aureus, L. monocytogenes, Alicylobacillus acidoterrestris, B. cereus*	Films	Barbosa et al. (2013)
Modified atmosphere packaging		Microbial reduction (molds, mesophilic bacteria and lactic acid bacteria)	Minimally processed apples, jackfruit	Biegańska-Marecik et al. (2004), Saxena et al. (2008)

microorganisms, gases, dust, insects, etc. In this sense, the use of improved new packaging is growing. Robertson (2006), defined the active packaging as "packaging in with subsidiary constituents have been deliberately included in or on either the packaging material or the package headspace to enhance the performance of the package system" (Vega-Lugo and Lim 2009), the smart or intelligent packaging is defined as "packaging that contains an external or internal indicator to provide information about aspects of the history of the package and/or the quality of the food" (Lee and Rahman 2014).

In the case of active packaging (AP), it can extend the shelf live. For smart packaging, on the contrary, it will be sensitive to changes in food, and detect internal or external product, and/or the surrounding environment, even the storage conditions (De Jong et al. 2005). It incorporates robust ways to control oxidation, microbial growth, and moisture (López-Gómez et al. 2009). Examples of active packaging and additives used are shown in Table 12.1.

Packaging with antimicrobial properties includes those in which the biopolymer has a natural antimicrobial activity (chitosan), or added with several antimicrobial agents (sorbic acid, propionic acid, bacteriocins, essential oils, etc.) (Campos et al. 2011). This biopolymer offers real potential for application in foods due to its short time biodegradability, antibacterial and antifungal activity, biocompatibility, and non-toxicity (Aider 2010). The polymers that form the packaging are

synthetical or biological. The synthetical packaging is derived of petroleum-based plastic materials. They are cheap and convenient to use with good processing property, good aesthetic quality, and excellent physic-chemical properties. The main disadvantage is the serious environmental problem that they represent since they are not easily degraded in the environment after their use (Espino-Díaz et al. 2010). There are several biopolymers used to packaging, mainly plant carbohydrates like starch, cellulose, chitosan, alginate, agar, among others, as well as soy protein, corn zein, wheat gluten, gelatin, collagen, casein, and the like. In previous years, microbial polysaccharides, such as pullulan, curdlan, poly (hydroxyalkanoates) have been added to the list (Rhim et al. 2013).

Among intelligent packaging (IP), there are many mechanisms and functionalities. In general terms, the IP is capable to detect, record, trace, and improve the quality and safety in several products, including minimally processed foods (González-Aguilar et al. 2009). The IP allows to make decisions about which product has expected quality characteristics. The main factor to consider in IP is the low cost, easy-to-read and easy-to-integrate in product chain (Yam et al. 2005). In general, there are two types of intelligent packaging: (1) measuring the condition of the package on the outside and (2) measuring the quality of food product directly inside the packaging. The characteristics of this packaging enables it to inform the manufacturer, retailer and consumer of the state of their food product properties (Restuccia et al. 2010).

12.3.1.2 Time Temperature Indicators (TTIs)

In minimally processed foods, the temperature is the most important environmental factor influencing the kinetics of physical, chemical and microbiological deterioration, this can be observed mainly during transportation and storage. The detection is based in acid-based reaction, melting, polymerization or biological activity through time and/or changes on temperature (Wanihsuksombat et al. 2010). There are three basic types of commercially available TTIs: Critical temperature indicator, partial history indicators, and full history indicators (Yam et al. 2005).

12.3.1.3 Freshness Indicator (FI)

The FI is based on the detection of volatile metabolites such as amines, ammonia, and carbon dioxide emitted during the aging of packaged food. In fish and meat, it uses an inexpensive and simple chemical sensor to allow the real time, non-invasive and non-destructive determination of freshness, based on a pH change. The colorimetric sensor is a dye with response to growth of bacteria, and change in color shows development. Other sensor concepts have been proposed, such as oxygen, amines, CO_2, ammonia, ethanol, H_2S (Puligundla et al. 2012; Kuswandi et al. 2011, 2013; Marek et al. 2012).

12.3.1.4 Nanotechnology in Minimally Processed Foods

Nanotechnology involves the characterization, fabrication and/or manipulation of structures, devices or materials that have at least one dimension or contain components with at least one dimension, which is 1–100 nm in length approximately (Duncan 2011; Bouwmeester et al. 2009). The food nanotechnology is still a less-known subfield of the greater nanotechnology spectrum. This area, involves improved taste, flavor, color, and texture, and the development of antimicrobial and new food packaging materials. There are three main fields or applications for nanotechnology in food packaging. Barrier applications of polymer nanocomposites, nanoparticle-based antimicrobials, and sensor/assays that detect contaminants in foods or monitoring changes in packaging condition or integrity (Duncan 2011).

Regarding packaging, nanotechnology strategies focus in the improvement of the barrier properties, addition and slow release of antimicrobial componens, and even use nanosensors to allow traceability of packaged products (Rhim et al. 2013).

To prevent humidity loss, water and gas diffusion, polymer nanocomposites (PNCs) have been developed. The nanocomposite systems are those in which the dispersed phase is nanostructured. These systems included nanosized antimicrobial agents. This material is created by dispersing an inert, nanoscale filler throughout a polymeric matrix. Nanoclays are naturally occurring aluminum silicate, primary composed of fine-gained minerals having natural structure with sheet-like geometry; they are inexpensive and eco-friendly. The popularity of nanoclays in food derives from their low cost, effectiveness, high stability, and alleged benignity. A typical example is the use of nanosized montmorillonite (MMT) clay (Kim 2008).

One of the great advantages that will be able to offer PNCs in the food packaging industry, including minimally processed foods, is to reduce costs, increasing shelf-life by decreasing oxygen transfer and water vapor, increasing mechanical properties and finally, a faster rate of biodegradation (Naffakh et al. 2013).

Despite the great advantages of this type of packaging, there are few studies regarding the increased shelf life and/or safety it provides. The main concern is the migration of nanoparticles or other substances from packaging to food when they are consumed. For films made with MMT/wheat gluten, it is allowed a certain amount of aluminum and silicon. However, some studies have shown inconclusive results, studies to determine toxicity levels and ensure consumers about the potential risks of their use should be conducted to determine its feasibility (Sorrentino et al. 2007).

12.3.2 Maintaining Key Sensory Attributes

Minimally processed commodities undergo rapid deterioration, in which their respiration activity and ethylene production increases, depending on the kind of product, cutting grade, and temperature. Since the rate of respiration indicates how

quickly a product may deteriorate, increased respiration by tissue injury results in a reduced shelf-life in fruits and vegetables. Furthermore, ethylene contributes to the biosynthesis of enzymes involved in fruit maturity; making it partially responsible for physiological changes in minimally processed products (Olivas et al. 2008). Minimally processed food operations damage the tissue integrity resulting in cellular disruption, contact of enzymes and substrates lead to biochemical injuries, which results in degradation of the primary quality attributes: color, texture and flavor (Rojas-Graü et al. 2009).

One major challenge that minimally processed products face is enzymatic browning. This requires the presence of four different components: oxygen, oxidizing enzyme, copper, and a suitable substrate. To prevent browning, at least one of these components must be removed from the system (Robles-Sánchez et al. 2013).

The key enzyme in enzymatic browning is polyphenol oxidase (EC 1.14.18.1; PPO). This enzyme catalyzes the hydroxylation of monophenols to o-diphenols and the oxidation of o-diphenols to o-quinones. This quinones lead to melanin accumulation, which is associated with browning in plant tissue reactions (Barbagallo et al. 2009). Another important family of oxidative enzymes is peroxidases (EC 1.11.1.7; POD). Although these enzymes may contribute to enzymatic browning, oxidizing hydrogen donors in the presence of hydrogen peroxide (H_2O_2) can play an important role as well (Toivonen and Brummell 2008; Richard-Forget and Gauillard 1997).

There are numerous chemical and physical preservation strategies that can be used to reduce enzymatic browning (Lozano 2006; McEvily et al. 1992). One of those strategies is modified atmosphere (Caleb et al. 2013a; Pirovani et al. 1997), controlled atmosphere storage due to high CO_2 atmospheres may help maintain pigment concentrations, by reducing plastid senescence (Caleb et al. 2013a), macroscopic decay, translucency and off-odors (Portela and Cantwell 1998).

Another preservation method is the use of edible coating which reduces decay, delays ripening and color changes, provides a semipermeable barrier against oxygen, carbon dioxide, moisture and solute movement; thereby reducing respiration, water loss, and oxidation reaction rates (Dávila-Aviña et al. 2011a), acting as a carrier of compounds like anti-browning agents (Olivas et al. 2007). Chemicals inhibitors are also being used, these chemical compounds exhibit different modes of action on preventing enzymatic browning, they include: reducing agents, chelating agents, and inorganic salts (Manolopoulou and Varzakas 2011). More recently, ascorbic acid, citric acid, chlorine dioxide, cysteine, 4-hexylresorcinol, sodium chlorite with added salicylic acid or cinnamic acid, have been reported to prevent enzymatic browning (Lu et al. 2007; Gómez-López et al. 2008; Chen et al. 2010; Ghidelli et al. 2012, 2013).

Accelerated loss of texture is considered one of the main factors that limits the shelf-life of fresh-cut tissue (Beaulieu and Gorny 2001). The texture breakdown of lightly processed tissue is influenced by physical wounding, induced increase in enzymes targeting cell walls decreases membrane integrity, which would cause the disruption of texture-related enzymes and their substrates (Huber et al. 2001;

Soliva-Fortuny et al. 2002). The softening process is mainly related to the activity of pectin methylesterase (PME, EC 3.1.1.11) (Banjongsinsiri et al. 2004; Guillemin et al. 2008) and polygalacturonase (PG, EC 3.2.1.15) (Rastogi et al. 2007). The rate of softening after processing depends on many factors related to the product, processing, and storage conditions (Martın-Belloso et al. 2006).

Another drawback of the fresh products or minimally processed packaged fruits and vegetables is the fact that flavor life is shorter than the postharvest life (Caleb et al. 2013b). Once the plant tissue is disrupted, enzymatic reactions allow the formation of volatile compounds such as alcohols, aldehydes, terpenes, esters and acids (Dávila-Aviña et al. 2011b). Volatile compounds also contribute to the formation of off-odors, depending on their concentration; they can shorten the storage life of the product as well (Poll et al. 2006).

Very often, the development of off-odors is one of the factors limiting the shelf-life of fresh-cut products, as has been observed in oranges (Rocha et al. 1995), melons (Bai et al. 2003), baby spinach (Tudela et al. 2013a), and iceberg lettuce (Tudela et al. 2013b). Cut fruit products rapidly lose their typical flavor, even when stored under refrigerated conditions (Voon et al. 2007). Temperature control is essential to maintain flavor and quality of fresh products (Deza-Durand and Petersen 2011; Tietel et al. 2012; Jacobsson et al. 2004). Poll (2006) stated that aldehydes in lower concentrations contribute to characteristic aromas in leeks but at higher concentrations can cause off-odors. Deza-Durand and Petersen (2011) investigated aroma compounds as a function of cutting direction and concluded that transverse cutting is a more severe method of preparation than longitudinal cutting, based on the increase in the levels of volatiles compounds produced through the LOX Enzymes like lipooxidase, which catalyzes peroxidation reactions, cause the formation of numerous bad-smelling aldehydes and ketones (Varoquaux and Wiley 1994).

12.3.3 Safety

New technologies to ensure quality, security, and availability of food are emerging. They have profound effects on the capacity to produce food with appropriate management of natural resources and environment. A number of technologies have been developed over the past century in the areas of molecular biology, nutritional science and food science, among others. Fields, like biotechnology, in which the application of molecular biology to a wide range of agricultural production problems have allowed scientists to develop crops with specific beneficial traits (Gregory et al. 2009; Taeymans 2000).

The food quality is a major concern today. Determining when a food is fit for consumption, the difficulty to detect the dangerous levels of contaminants and/or decrease of quality, is one of the main reasons why sensors have been developed (Avella et al. 2011). In minimally processed foods, it is important to know if the food

is fresh or if there is a risk of presence of spoilage microorganisms or pathogens that reduce the shelf life.

The recent developments in sensors systems include oxygen indicators, freshness indicator, and pathogen sensors. Among those, there is listed a UV-activated colorimetric oxygen indicator, which uses nanoparticles of TiO_2 to photosensitize the reduction of methylene blue by triethanolamine in a polymer encapsulation medium, using UV light it reflects changes that take place in the fresh food product as a result of the microbiological growth (Silvestre et al. 2011). Another example of gas sensing related to food safety or quality, includes the detection of gaseous amines by fluorescence quenching of nanofibrils of perylene-based fluorophores, detection of volatile organics, including acetone, and ethanol and carbon monoxide and nanocomposites to detect ethylene gas (Duncan 2011).

In recent decades, there has been an interest in developing not only biodegradable packaging but that can also prolong the shelf-life of the product by adding components such as antimicrobial or addition of compounds to detect changes in the development of microorganisms (Ramos et al. 2013).

The main characteristic of this type of packaging is the incorporation of components that would release or absorb substances into, or from, the packaged food, or the environment surrounding the food. Metal nanoparticles, metal oxide materials and carbon nanotubes are the most used to develop antimicrobial active packaging (Wang et al. 2012).

Silver, gold, and zinc nanoparticles are the most studied metal nanoparticles with antimicrobial functions. The ways that silver nanoparticles behave are by adhering to the cell surface, degrading lipopolysaccharides and forming pits in the membranes, penetrating inside bacterial cells causing DNA damage, and releasing antimicrobial Ag^+ ions, which bind to electron donor groups in molecules containing sulphur, oxygen or nitrogen (Silvestre et al. 2011).

The manner in which the nanomaterial protects the food is coating in the matrix of the packaging material or near the food product or utilizing antimicrobial macromolecules with film forming properties or edible matrices. Several reports showed that chitosan in addition to organic acid (sorbic, acetic, aminobenzoic or lactic) in nano-sized solubilisates, showed differential antimicrobial activity against several pathogenic bacteria (Cruz-Romero et al. 2013).

Nanotechnology applied in food, medical and health industry have several beneficial effects, but is still unclear what would be the long-term toxic effects. In this sense, it is necessary not only to develop new nanomaterial, but also conducting studies to assess adverse effects for consumers (Maynard 2007).

There are three different ways of entrance of nanoparticles into organisms: inhalation, entrance, through skin, and ingestion. In nanomaterials for food packaging many people fear risk of indirect exposure due to potential migration of nanoparticles from packaging.

The main reason for this fear is the lack of tools utilized to estimate the level of exposure due to ingestion in the case that the nanoparticles migrate to food and then to the consumer. There are not enough studies about the nanoparticles migration to food.

Some studies have reported that free nanoparticles can cross cellular barriers and that exposure to some of these nanoparticles may lead to oxidative damage and inflammatory reactions (Chaudhry et al. 2008; Bouwmeester et al. 2009).

12.3.4 Regulations

Until recently, most systems for regulating food safety were based on legal definitions of unsafe food, enforcement of programs to remove the unsafe food from the market, and sanctions for the responsible parties. These traditional systems cannot respond to existing and emerging challenges to food safety because they do not provide or stimulate a preventive approach. In the past, there was a transition to risk analysis based on better scientific knowledge of food borne illness and its causes. This provides a preventive base for regulatory measures for food safety at both national and international levels. The risk-based approach must be supported by information on the most appropriate and effective means to control food borne hazards (Rosegrant and Cline 2003).

All these changes lead to situations in which a single source of contamination can widespread, even with global consequences. Developing countries in particular are experiencing rapid changes in their health and social environments, and the strains on their limited resources are complicated by expanding urbanization, increasing dependence on stored foods and insufficient access to clean water and facilities for safe food preparation (WHO 2002).

The FDA FSMA (Food Safety Modernization Act) sections include the preventive control plans where the food manufacturing facilities must develop and implement written science-based plans that evaluate hazards that could affect food safety. In addition, the mandatory states safety standards created by the FDA and establishes science-based minimum standards for the correct production and harvesting of horticultural products. The mandatory inspections of food facilities are based on risk, and all high-risk domestic facilities must be inspected within 5 years of enactment and no less than 3 years thereafter. FDA is required to establish a comprehensive product tracing system to track movement of food products from farm to point of sale or service. The goal is to identify sources of food borne illnesses earlier and contain outbreaks more quickly.

To assure the quality and security of food, there is a third-party certification where designated imported foods must be certified by a third party with expertise in food safety under the oversight of FDA. At the same time, a certification is necessary for high-risk food because FDA requires that high-risk imported foods have to be accompanied by a credible third-party certification or other assurance of compliance as a condition to get into the U.S. In case of any problem, the process named mandatory recall requires a recall from authorities based on a "reasonable probability" that an article of food is adulterated, misbranded or will cause "serious adverse health consequences or death" to people or animals, and finally the suspension of registration if it is determined that the food has a reasonable probability of serious adverse health consequences or death. A facility that is under suspension is prohibited from distributing food (Ades et al. 2012).

12.3.5 Key Challenges

According to the WHO and FAO (2009), the key challenges to all kinds of foods including minimally processed foods are:

1. Increased investment in people is essential to accelerate food security improvements. In agricultural areas, education works directly to enhance the ability of farmers to adopt more advanced technologies and crop-management techniques (Rosegrant and Cline 2003).
2. To avoid or eradicate hunger in the earth. Not only to ensure sufficient food production to feed a world population that will grow by 50 % and reach 9 billion by 2050 (FAO 2002), but also to find ways to guarantee that everyone has access to the food they need for an active and healthy life.
3. To put in place a more coherent and effective system of governance of food security, at both national and international levels.
4. To make sure developing countries have a fair chance of competing in world commodity markets and that agricultural support policies do not unfairly distort international trade.
5. To find ways to ensure that farmers, in both developed and developing countries, can earn incomes comparable to those of secondary and tertiary sector workers in their respective countries.
6. To mobilize substantial additional public and private sector investment in agriculture and rural infrastructure and ensure farmers' access to modern inputs to boost food production and productivity in the developing world, particularly in low-income and food-deficit countries.
7. To ensure that countries are prepared to adapt to climate change and mitigate negative effects (FAO 2009).
8. Advances and improvements in public health signal detection using PulseNet (www.cdc.gov/pulsenet/), which is a system whereby state public health laboratories analyze strains of certain pathogenic bacteria from ill individuals and determine their genetic fingerprint. This is then shared nationally with the Centers for Disease Control and Prevention (CDC), allowing CDC to analyze results and when the same genetic fingerprint of an organism is isolated from clinical specimens from geographically dispersed regions. Several multistate outbreaks have been detected due to PulseNet and this collaboration to improve signal detection.
9. New regulatory reporting requirements of contaminated food products in commerce (The Reportable Food Registry).
10. Improved communication streams and interconnectivity between regulatory agencies domestically and internationally.
11. The global food supply continues to grow in volume and complexity. Imports are expected to continue to grow because of cost concerns (need for lower costs and higher productivity), availability (includes seasonality) and consumer demand for diverse food products. According to an FDA Report entitled "Pathway to Global Safety and Quality," (FDA 2011) between 10 and 15 % of

all food consumed in the U.S. is imported. According to the U.S. Government Accountability Office (GAO), imports account for nearly two-thirds of the fruits and vegetables and 80 % of seafood eaten domestically.

12. As a regulatory perspective, several new laws and regulations have been issued to help address the safety of the global food supply chain, including the Bioterrorism Act of 2002 (FDA 2009).

12.4 Conclusion

Consumers' habits and life style are evolving continually. The consumption of minimally processed foods has increased. New trends in food processes have been proposed to obtain a product closer to fresh food products allowing the consumer to have food with a long shelf-life through a combination of factors for conservation. Research on minimally processed products needs to cover many areas, not only regarding food safety and security, but also relative to deteriorative reactions, physic-chemical changes and nutritional impact, improvements in these areas still remain a big challenge. Emerging new technologies have shown good results and its implementation in a larger scale is in the horizon. Research activities should therefore be supported further in order to contribute to innovation and the wealth of society. Worldwide organizations, supported by all existing expertise in the private and public sectors should provide technical assistance to fill the knowledge gap and contribute to the availability of safe and nutritious foods worldwide.

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