Microbial Food Spoilage: Control Strategies for Shelf Life Extension

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Abstract Food spoilage can be defined as any sensory change in food flavor which the consumer considers to be unacceptable. Spoilage may arise from insect damage, physical damage (freezing, drying, etc.), chemical changes (usually involving oxygen), and indigenous enzyme activity in the animal or plant tissue. Spoilage is therefore complex and may occur at any stage along the food chain. Bacteria, fungi, yeast, and insects are the main cause for food spoilage. There are a wide range of metabolites produced during microbial spoilage including alcohols, sulfur compounds, hydrocarbons, fluorescent pigments, as well as organic acids, esters, carbonyls, and diamines. Preservation of food for its safety and long shelf life is dependent on the food type and properties (pH, water activity, nutrient content, antimicrobial constituents, etc.), initial microbial flora, and processing and storage conditions (heating, acidification, reduced water activity, storage atmosphere, chilled storage, etc.). This review deals with food spoilage, microbes causing food contamination, prevention of microbial spoilage, and preservation of foods.

1 Introduction

Food spoilage can be defined as any sensory change (tactile, visual, olfactory, or flavor) which is considered unacceptable by the consumer. Spoilage may occur at any stage along the food chain and may arise from (a) insect damage, (b) physical damage (bruising, freezing, drying, etc.), (c) indigenous enzyme activity, and (d) chemical changes (usually involving oxygen). Spoilage is, therefore, complex

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and involving physical, chemical, biochemical, and biological changes (Voysey 2007). The main reason for food deterioration is due to microorganisms that will cause spoilage and decay. These include Gram-positive and Gram-negative bacteria, yeasts, and molds. Gram-negative rod-shaped bacteria such as *Acinetobacter*, *Aeromonas*, *Alcaligenes*, *Alteromonas*, *Flavobacterium*, *Moraxella*, and *Achromobacter* may grow at cold temperatures and have been shown to contribute to the spoilage of chilled red meat, cured meats, poultry, fish, shellfish, milk, and dairy products (Voysey 2007). *Vibrio* spp. are halophilic bacteria (salt loving) that may therefore cause spoilage of seafish and cured meats. Microbial spoilage includes (a) visible mold growth, (b) production of gas, (c) diffusible pigment and enzymes which may cause softening and rotting (proteolysis), and (d) slime, off-odor, and off-flavor (Voysey 2007). There are a wide range of metabolites produced during microbial spoilage, including alcohols, sulfur compounds, ketones, fluorescent pigments, organic acids, as well as esters, carbonyls, and diamines.

Spoilage is generally most rapid in proteinaceous chilled fresh foods (e.g., red meats, poultry, fish, and dairy products) due to (a) high nutrition, high moisture content, and relatively neutral pH. Other fresh foods that may suffer significant spoilage are fruit and vegetables. Fruits are generally spoiled by yeast and molds, as the low pH prevents bacterial growth. Vegetables are frequently subjected to both bacterial and fungal spoilage. Suitably processed (and packaged) or ambient stable foods with a low moisture content will be expected to show little sign of microbial spoilage by yeasts or molds. On the other side, food loss, from farm to consumer, causes considerable environmental and economic effects. The USDA Economic Research Service estimated that more than 96 billion pounds of food in the USA were lost by retailers, foodservice, and consumers in 1995 (Doyle 2007; Kantor et al. 1997). Factors that changed food science and technology include (a) canning, where it revolutionized food preservation and made it more available; (b) commercial freezing and refrigeration which allowed preservation of meats; (c) food additives such as antimicrobials, antioxidants, benzoates, sorbitol, etc.; and (d) refrigerated railcars and trucks which increased the availability of fresh fruits, vegetables, and meats. This review deals with food spoilage, food poisoning, causal microorganisms, as well as preservation strategies for long shelf life of foods.

2 History of Food Preservation

Throughout the history of mankind, science, bringing new discoveries, allowed our lives to become healthier, more efficient, and safer, and at the same time, more dangers are possible. As early as the beginning of the nineteenth century, major breakthroughs in food preservation had begun. Soldiers and seamen, fighting in Napoleon's army, were living off salt-preserved meats. These foods, however, provided nutritional value, but frequent outbreaks of scurvy were developing (Harris and Von Lesecke 1973). To try and solve the problem, Napoleon began the search for a better mechanism of food preservation and offered 12,000 francs to the person who devised a safe and dependable food preservation process for foods to remain fresh and wholesome for long periods of time. A Parisian confectioner named Nicolas Appert, who had been experimenting with food all his life, produced a satisfactory method and collected the prize in 1809 from the great Napoleon himself (Harris and Von Lesecke 1973). He observed that food heated in sealed containers was preserved as long as the container remained unopened or the seal did not leak. This became the turning point in food preservation history. Fifty years following the discovery by Nicolas Appert, another breakthrough had developed. Another Frenchman, named Louis Pasteur, noted the relationship between microorganisms and food spoilage. This breakthrough increased the dependability of the food canning process (Harris and Von Lesecke 1973). As the years passed, new techniques assuring food preservation would come and go, opening new doors to further research.

3 Food Spoilage

Food spoilage can be defined as a disagreeable change in a food's normal state. Food spoilage is a metabolic process that causes foods to be undesirable or unacceptable for human consumption due to changes in sensory characteristics. Such changes can be detected by smell, taste, touch, or sight (Sherratt et al. 2006). Spoiled foods may to be not hazardous and cause no illness if they are free of pathogens or toxins. However, changes in texture, smell, taste, or appearance cause them to be rejected. Changes in food, either through growth of microorganisms or enzyme deterioration of food, will lead to unsafety and spoilage of foods. The rate of deterioration depends on a variety of factors which must be controlled carefully (Food Poisoning. A fact of life 2009).

3.1 Factors Causing Spoilage

Some spoilage is inevitable, and a variety of factors cause deterioration of foods including: (1) Endogenous enzymes in plants oxidizing phenolic compounds (browning) or degrading pectins (softening). (2) Rodent and insect damage that may provide an entry point for microbial growth on foods. (3) Parasites, when visible, for example, in meat or fish, rendering food undesirable. (4) Microbes (bacteria, molds, yeasts) growing on and metabolizing foods. (5) Light causing degradation of pigments, fats, and proteins (off-flavors and off-odors) or stimulating pigment production (greening of potatoes). (6) Temperature, both excessive heat and freezing, physically affecting texture of foods and breaking emulsions. (7) Air, particularly oxygen, oxidizing lipids producing strong off-odors and off-flavors. (8) Too little moisture causing cracking, crumbling, or crystallization in contrast to moisture in excess causing sogginess, stickiness, or lumping (Voysey

2007; Doyle 2007). These factors are interrelated, as certain temperatures, oxygen, and moisture levels increase the activities of endogenous enzymes. Types of food decay are discussed below (Spoilage of Food. Home.pacific.nethk/ppleung/chem/preservation.htm).

3.1.1 Putrefaction

During this type, biological decomposition of organic matter with production of ill-smelling and ill-tasting products occurs, associated with anaerobic organisms (no oxygen present). Proteins are degraded by proteolytic microorganism, where hydrogen sulfide, amino acids, and ammonia are produced.

3.1.2 Fermentation

Through which chemical changes in organic substances are produced by the action of enzymes. This general definition includes virtually all chemical reactions of physiological importance, and scientists today often restrict the term to the action of specific enzymes, called ferments, produced by minute organisms such as molds, bacteria, and yeasts. For example, lactase, a ferment produced by bacteria usually found in milk, causes the milk to be sour by changing lactose (milk sugar) into lactic acid.

3.1.3 Rancidity

Rancidity includes three types: microbial rancidity, hydrolytic rancidity, and oxidative rancidity. Microbial rancidity occurs due to deterioration changes of fats with time, which result in undesirable flavors and odors. These changes in fats are given the term rancidity. Fatty acids are formed through hydrolysis of the lipid (fat) by the water it contains. Some of the liberated fatty acids are volatile, and some have very unpleasant odors and flavors. The oxidation of acylglycerols which occurs in air, without the presence of enzymes, is called autoxidation. Among the products of autoxidation are hydroperoxides which have no taste, but they decompose easily to form aldehydes, ketones, and acids, which give oxidized fats and oils their rancid flavors.

3.2 High-Risk Foods

Some foods are highly risky, as they provide the ideal conditions needed for growth of microorganisms. These foods include meat, meat products, milk, dairy products, as well as fruit and marine foods (fish, shrimp, crab, etc.). If such foods became contaminated with food poisoning microorganisms, and conditions allow them to multiply, the risk of food poisoning increases. People at high risk are elderly people, babies, and pregnant as they need to be extra careful about the foods. People with low resistance to infection should avoid high-risk foods such as meat products, marine foods, and unpasteurized soft cheese (Food Poisoning. A fact of life 2009).

3.3 Detection of Food Spoilage

Spoilage is manifested by a variety of sensory cues such as off-colors, off-odors, softening of vegetables and fruits, and formation of slime. However, even before it becomes obvious, microbes have begun the process of breaking down food molecules for their own metabolic needs (Doyle 2007). Sugars and easily digested carbohydrates are used first; plant pectins are then degraded. Proteins are attacked producing volatile compounds with characteristic smells such as ammonia, amines, and sulfides. These odors start to develop in meat when there are about 10^7 CFU of bacteria/cm^2 of meat surface and are usually recognizable at populations of 10^8 CFU/cm^2 (Ellis and Goodacre 2006). Early detection of spoilage would be advantageous in reducing food loss because there may be interventions that could halt or delay deterioration, and on the other hand food that had reached the end of its designated shelf life but was not spoiled could still be used. Numerous methods for detection of spoilage have been devised with the goals of determining concentrations of spoilage microbes or volatile compounds produced by these microbes. However, many of these methods are considered inadequate because they are time-consuming or labor-intensive and/or do not reliably give consistent results (Doyle 2007).

Detection of volatile compounds produced by spoilage bacteria can be a less invasive and more rapid means for monitoring spoilage. Biogenic amines (putrescine, cadaverine, histamine, and tyramine) are commonly produced during spoilage of high protein foods and can attain levels that cause illness, particularly in spoiled fish. HPLC methods have been used to quantitate different amines in fish (Baixas-Nogueras et al. 2005), chicken (Balamatsia et al. 2006a), and cheese (Innocente et al. 2007). Combined concentrations of these amines are expressed as a biogenic amine index that is related to the extent of food spoilage and to the concentrations of spoilage organisms.

Other techniques being developed to detect microbes or chemicals associated with spoilage include (a) FT-IR (Fourier transform infrared spectroscopy) used with beef (Ellis et al. 2004) and apple juice (Lin et al. 2005), (b) visible and short-wavelength near-infrared spectroscopy to detect microbial load in chicken by diffuse reflectance (Lin et al. 2005), (c) ion mobility spectrometry for detecting trimethylamine in meat (Bota and Harrington 2006), and (d) gas chromatography-mass spectrometry for analyses of fish. It is expected that some advances in nanotechnology will improve the portability, sensitivity, and speed of detection systems.

3.4 *Food Spoilage Microorganisms*

Chemical reactions that cause offensive sensory changes in foods are mediated by a variety of microbes that use food as a carbon and energy source. These organisms include prokaryotes (bacteria), single-celled organisms lacking defined nuclei and other organelles, and eukaryotes, single-celled (yeasts) and multicellular (molds) organisms with nuclei and other organelles (Doyle 2007). Some microbes are commonly found in many types of spoiled foods, while others are more selective in the consumed foods; multiple species are often identified in a single spoiled food item, but there may be one species (a specific spoilage organism) primarily responsible for production of the compounds causing off-odors and off-flavors. Some microbes, such as lactic acid bacteria and molds, secrete compounds that inhibit competitors (Gram et al. 2002). Spoilage microbes are often common inhabitants of soil, water, or the intestinal tracts of animals and may be dispersed through the air and water and by the activities of small animals, particularly insects. It should be noted that with the development of new molecular typing methods, the scientific names of some spoilage organisms, particularly the bacteria, have changed in recent years, and some older names are no longer in use (Gram et al. 2002). Spoilage microorganisms are discussed below.

3.4.1 Yeasts

Fungi include molds and mushrooms. Yeasts are a subset of fungi and are generally single-celled facultative organisms (capable of growth with or without oxygen) and adapted for life in liquid environments. Unlike some molds and mushrooms, yeasts do not produce toxic secondary metabolites. Yeasts are well known for their beneficial fermentations that produce bread and alcoholic drinks. They often colonize foods with a high sugar or salt content and contribute to spoilage of pickles, fermented foods, and some dairy products. Fruits and juices with a low pH are another target, and there are some yeasts that grow on the surfaces of meat and cheese (Doyle 2007; Smits and Brul 2005). There are four main groups of spoilage yeasts: (a) *Saccharomyces* spp.: spoil wines and other alcoholic beverages by producing gassiness, turbidity, and off-flavors associated with hydrogen sulfide and acetic acid (Loureiro and Malfeito-Ferreira 2003; Restuccia et al. 2006; Siegmund and Pollinger-Zierler 2006).. (b) *Zygosaccharomyces*: are the usual spoilage organisms in foods such as salad dressings, dried fruit, jams, and soy sauce (Castro et al. 2003; Martorell et al. 2007; Meyer et al. 1989). They usually grow slowly, producing off-odors and off-flavors and carbon dioxide that may cause food containers to swell and burst. (c) *Candida* and related genera: are a heterogeneous group of yeasts, some of which also cause human infections. They are involved in spoilage of fruits, some vegetables, and dairy products (Casey and Dobson 2003; Fitzgerald et al. 2004). (d) *Dekkera/Brettanomyces*: are principally involved in spoilage of fermented foods, including alcoholic beverages and some dairy products. They can produce volatile phenolic compounds responsible for off-flavors (Loureiro and Malfeito-Ferreira 2003; Couto et al. 2005).

3.4.2 Molds

Molds are filamentous fungi that do not produce large fruiting bodies like mushrooms. Molds are very important for recycling dead plant and animal remains in nature but also attack a wide variety of foods and other materials useful to humans. Molds are well adapted for growth on and through solid substrates, generally produce airborne spores, and require oxygen for their metabolic processes. Most molds grow at a pH range of 3–8 (Doyle 2007). Spores can tolerate harsh environmental conditions, but most are sensitive to heat treatment. An exception is *Byssochlamys*, whose spores have a D value of 1–12 min at 90 °C (Doyle 2007). Molds have a diverse secondary metabolism producing a number of toxic and carcinogenic mycotoxins. Some spoilage molds are toxigenic, while others are not (Pitt and Hocking 1997). Spoilage molds can be categorized into four main groups:

A. *Zygomycetes* are widespread in nature, growing rapidly on bread, simple carbon sources in soil, and plant debris. *Zygomycetes* generally require high water activities for growth. The most common spoilage species are *Mucor* and *Rhizopus*. Zygomycetes are not known for producing mycotoxins, but there are some reports of toxic compounds produced by a few species (Doyle 2007). Some zygomycetes are also utilized for production of fermented soy products, enzymes, and organic chemicals (Voysey 2007).
B. *Penicillium* and related genera are distinguished by their reproductive structures that produce chains of conidia. Although *Penicillium* spp. can be useful to humans in producing antibiotics and blue cheese, many species cause spoilage fruits and vegetables, including cereals (Doyle 2007). Some species produce potent mycotoxins (patulin, ochratoxin, citreoviridin, penitrem). *Penicillium* spp. cause visible rots on citrus, pear, and apple fruits and cause enormous losses in these crops. Other species can attack refrigerated and processed foods such as jams and margarine (Voysey 2007). A related genus, *Byssochlamys*, is the most important organism causing spoilage of pasteurized juices because of the high heat resistance of its spores (Voysey 2007).
C. *Aspergillus* and related molds are more resistant to high temperatures and low water activity than *Penicillium* spp. and tend to dominate spoilage in warmer climates. Many aspergilla produce mycotoxins: aflatoxins, ochratoxin, territrems, and cyclopiazonic acid. *Aspergillus* spp. spoil a wide variety of food and non-food items (paper, leather, etc.) but are probably best known for spoilage of grains, dried beans, peanuts, tree nuts, and some spices (Doyle 2007).

D. *Fusarium* spp. cause plant diseases and produce several important mycotoxins but are not important spoilage organisms. However, their mycotoxins may be present in harvested grains and pose a health risk (Doyle 2007).

3.4.3 Bacteria

Bacterial species comprise a wide range of Gram-positive and Gram-negative strains. Gram-positive bacteria include spore- and non-spore-forming species.

Gram-Positive Spore-Forming Bacteria

Spore producers are usually associated with spoilage of heat-treated foods because their spores can survive high processing temperatures. These Gram-positive bacteria may be strict anaerobes or facultative (Voysey 2007). **Thermophilic** spore-forming bacteria prefer growth at high temperatures as high as 55 °C. Some thermophiles (*Bacillus* and *Geobacillus* spp.) cause sour spoilage of high or low pH canned foods with little or no gas production (Pepe et al. 2003). **Mesophilic** anaerobes, grown at ambient temperatures, cause several types of spoilage of vegetables (*Bacillus* spp.); putrefaction of canned products, early blowing of cheeses, and butyric acid production in canned vegetables and fruits (*Clostridium* spp.); and medicinal flavors in canned low-acid foods (*Alicyclobacillus*) (Chang and Kang 2004). **Psychrotolerant** spore-forming bacteria produce gas and sickly odors in chilled meats and brine-cured hams (*Clostridium* spp.), while others produce off-odors and gas in vacuum-packed, chilled foods and milk (*Bacillus* spp.) (Chang and Kang 2004).

Gram-Positive Lactic Acid Bacteria

Lactic acid bacteria are a group of Gram-positive bacteria, including species of *Lactobacillus*, *Pediococcus*, *Leuconostoc*, and *Oenococcus*, some of which are useful in producing fermented foods such as yogurt and pickles (Doyle 2007). However, under low oxygen, low temperature, and acidic conditions, these bacteria become the predominant spoilage organisms on a variety of foods. Undesirable changes caused by lactic acid bacteria include greening of meat and gas formation in cheeses (blowing), pickles (bloater damage), and canned or packaged meat and vegetables. Off-flavors described as mousy, cheesy, malty, acidic, buttery, or liver-like may be detected in wine, meats, milk, or juices spoiled by these bacteria. Lactic acid bacteria may also produce large amounts of an exopolysaccharide that causes slime on meats and ropy spoilage in some beverages (Doyle 2007).

Gram-Negative Enterobacteriaceae

Enterobacteriaceae are facultatively anaerobic bacteria that include a number of human pathogens such as *Salmonella*, *E. coli*, *Shigella*, and *Yersinia*, as well as a large number of spoilage organisms. These bacteria are widespread in nature in soil, on plant surfaces, and in digestive tracts of animals and are therefore present in many foods. *Erwinia carotovora* is one of the most important bacteria causing soft rot of vegetables in the field or those stored at ambient temperatures. Biogenic amines are produced in meat and fish by several members of this group, while others produce off-odors or off-colors in beer (*Obesumbacterium*), bacon and other cured meats (*Proteus*, *Serratia*), cheeses (several genera), coleslaw (*Klebsiella*), and shell eggs (*Proteus*, *Enterobacter*, *Serratia*). Temperature, salt concentration, and pH are the most important factors determining which, if any, of these microbes spoil foods (Doyle 2007). Many Gram-negative bacteria, including pseudomonads and enterobacteriaceae, secrete acyl homoserine lactones to regulate the expression of certain genes, such as virulence factors, as a function of cell density. These acyl homoserine lactones quorum-sensing signals may regulate proteolytic enzyme production and iron chelation during spoilage of some foods (Rasch et al. 2005).

Gram-Negative *Pseudomonas*

Pseudomonas and related genera are aerobic group of rod-shaped bacteria, some of which can degrade a wide variety of unusual compounds. They generally require a high water activity for growth, inhibited by pH values less than 5.4 and grown rapidly (psychrophilic) at 3–10 °C (Voysey 2007). Four species of *Pseudomonas* (*P. fluorescens*, *P. fragi*, *P. lundensis*, and *P. viridiflava*), as well as *Shewanella putrefaciens* and *Xanthomonas campestris*, are the main food spoilage organisms in this group. Soft rots of plant-derived foods occur when pectins that hold lyase enzymes are secreted by *X. campestris*, *P. fluorescens*, and *P. viridiflava* (Doyle 2007). These two species of *Pseudomonas* comprise up to 40 % of the naturally occurring bacteria on the surface of fruits and vegetables and cause nearly half of post-harvest rot of fresh produce stored at cold temperatures. The strains, *P. fluorescens*, *P. fragi*, and *P. lundensis*, cause spoilage of animal-derived foods (meat, fish, milk) by secreting lipases and proteases that cause formation of sulfides and trimethylamine (off-odors) and by forming biofilms (slime) on surfaces (Doyle 2007).

Other bacterial species are associated with spoilage of chilled, high protein foods such as meat, fish, and dairy products. They may not be the predominant spoilage organisms but contribute to the breakdown and decay of food components and may produce off-odors. Most species are aerobic although some grow at low oxygen levels and may survive vacuum packaging (Voysey 2007; Doyle 2007). Some examples include (a) *Acinetobacter* and *Psychrobacter*, which are predominant bacteria on poultry carcasses on the processing line and have been isolated from a variety of spoiled meat and fish. *Acinetobacter* grows at a pH as low as 3.3 and has been detected in spoiled soft drinks. These two genera do not produce extracellular lipases, hydrogen sulfide, or trimethylamine (fishy odor) and so are considered to have a low spoilage potential (Doyle 2007). (b) *Alcaligenes* is a potential contaminant of dairy products and meat and has been isolated from rancid butter and milk with an off-odor. These bacteria occur naturally in the digestive tract of some animals and also in soil and water. (c) *Flavobacterium* is found widely in the environment and in chilled foods, particularly dairy products, fish, and meat. It uses both lipases and proteases to produce disagreeable odors in butter, margarine, cheese, cream, and other products with dairy ingredients (Voysey 2007). (d) *Moraxella* and *Photobacterium* are important constituents of the microflora on the surface of fish. *Photobacterium* can grow and produce trimethylamine in ice-stored, vacuum-packaged fish (Doyle 2007).

4 Food Poisoning

There are thousands of cases of food poisoning each year, many of which are not reported or recorded in official statistics. Food poisoning may result from poor domestic food preparation, or poor food processing in industry. This may result in loss of business and people's jobs if it is a serious outbreak. Microorganisms occur naturally in the environment; on cereals, vegetables, fruit, animals, people, water, and soil; and in the air (Food Poisoning. A fact of life 2009). Most bacteria are harmless, but a small number can cause illness. Food which is contaminated with food poisoning microorganisms missed normal taste and smell. Food poisoning can be mild or severe. The symptoms will be different depending on what type of bacteria is responsible. Common symptoms include severe vomiting, diarrhea, exhaustion, headache, fever, and abdominal pain (Food Poisoning. A fact of life 2009).

4.1 Causal Factors for Food Poisoning

Some common factors leading to food poisoning include (1) poor hygiene, (2) preparation of food too far in advance, (3) frequent cooling and thawing, (4) infected food handlers, (5) contaminated processed food, (6) improper warm holding, and (7) consuming infected raw food. Sources of spoilage microorganisms include soil, water, air, dust, animal hides, the gastrointestinal tract, plant products, as well as food handlers, food utensils, and processing equipment (Food Poisoning. A fact of life 2009).

4.2 Food Poisoning Microorganisms

Food poisoning can be caused by eating food contaminated with bacteria, viruses, chemicals, or poisonous metals such as lead or cadmium. Most food poisoning, however, is caused by bacteria. Food which has become contaminated with harmful bacteria does not always taste bad. Most of the time it looks, smells, and tastes like it normally does (Doyle 2007). When someone swallows bacteria that cause food poisoning, there is a delay (incubation period) before symptoms begin. This is because most bacteria that cause food poisoning need time to multiply in the intestine (Food Poisoning Bacteria—*Salmonella, Listeria, E. coli* 0157, *Campylobacter*. info@www.accepta.com). The length of the incubation period depends on the type of bacteria, where it sticks to the lining of the intestine and can destroy cells by production of toxins (poisons) which absorbed and cause damage. Because bacteria enter the body through the digestive system, symptoms will generally be nausea, vomiting, abdominal cramps, and diarrhea (Australian Government 2010). In some cases, food poisoning can cause very serious illness or even death. Most common types of food poisoning bacteria are discussed below.

4.2.1 *Clostridium botulinum*

These bacteria are found in the soil and in the inadequately processed canned meat, vegetables, and fish (faulty canning). Food poisoning caused by clostridium bacteria is important to know about because these bacteria are common in the environment. Food poisoning by clostridium can be gotten from poor food handling practices in the home, in the factory, or in a food outlet, especially relating to cooking and storage/refrigeration temperatures. *Clostridium* food poisoning symptoms occur about 12 h after eating a contaminated food (Australian Government 2010). Symptoms include stomach pains, diarrhea, drooping eyelids, and sometimes nausea and vomiting. Symptoms last about 24 h. One type of clostridium bacteria produces a very serious food poisoning disease called botulism. This disease is caused by eating food which is contaminated with an extremely poisonous toxin produced by the bacteria *Clostridium botulinum*. Unless properly treated, death occurs within 3–7 days or a slow recovery over months.

4.2.2 *Staphylococci*

These bacteria are found on the skin, in sores, in infected eyes, and in the nose, throat, saliva, and bowel of humans. There may be many of these bacteria in the yellow mucus (slimy substance) which comes from the nose or is coughed up when a person has a cold or a lung infection (Australian Government 2010). *Staphylococci* do not cause illness until they get onto food and grow and multiply. While they are doing this, they produce a toxin (poison). It is the toxin which causes the illness. The toxin is not destroyed by cooking the food. Symptoms of *Staphylococcus* food poisoning usually appear between 1 and 8 h after eating the infected food.

4.2.3 *Campylobacter*

These bacteria are found in many animals including dogs, cats, cattle, and poultry. The sources of infection from these bacteria are usually contaminated food and water. Infection can occur from ingestion of contaminated food or water (especially undercooked chicken and creek or river water), contact with infected animals (especially puppies or kittens with diarrhea), or poor food handling (especially by using the same chopping boards, knives, and plates for raw and cooked chicken) (Australian Government 2010). Campylobacter food poisoning symptoms usually last from 2 to 5 days. These include diarrhea, severe abdominal pain, vomiting, and fever. It is a serious disease in indigenous communities because of the possibility of dehydration from diarrhea.

4.2.4 *Escherichia coli*

Escherichia coli is the most prevalent infecting organism in the family of Gram-negative bacteria known as enterobacteriaceae (Barry and Dori 2000). *Escherichia coli* bacteria were discovered in the human colon in 1885 by German bacteriologist Theodor Escherich (Feng et al. 2002). Dr. Escherich also showed that certain strains of the bacterium were responsible for infant diarrhea and gastroenteritis, an important public health discovery. Although *E. coli* bacteria were initially called *Bacterium coli*, the name was later changed to *Escherichia coli* to honor its discoverer (Feng et al. 2002). *Escherichia coli* is often referred to as the best or most-studied free-living organism (Barry and Dori 2000; James 2000). More than 700 serotypes of *E. coli* have been identified (Barry and Dori 2000; Griffin and Tauxe 1991). The "O" and "H" antigens on the bacteria and their flagella distinguish the different serotypes (Griffin and Tauxe 1991). Most strains of *Escherichia coli* are harmless, but those that produce verocytotoxin (called verocytotoxin-producing *E. coli*, or VTEC) can cause severe illness (Food Poisoning Bacteria—*Salmonella, Listeria, E. coli* 0157, *Campylobacter*. info@accepta.com).

E. coli bacteria normally live in the intestines of humans and animals. It is also found in high-risk foods such as raw meat and dairy products. Although most strains of these bacteria are harmless, several are known to produce toxins that can cause diarrhea. One particular *E. coli* strain signed 0157:H7 can cause severe diarrhea and kidney damage (Food Poisoning Bacteria—*Salmonella, Listeria, E. coli* 0157, *Campylobacter*. info@accepta.com). Diarrhea, which may contain blood, can lead to kidney failure or death. It is important to remember that most kinds of *E. coli* bacteria do not cause disease in humans. Indeed, some *E. coli* are beneficial, while some cause infections other than gastrointestinal infections, such as urinary tract infections (Barry and Dori 2000). The *E. coli* that are responsible for the numerous reports of contaminated foods and beverages are those that produce Shiga toxin, so called because the toxin is virtually identical to that produced by *Shigella* dysenteriae type 1 (Griffin and Tauxe 1991). The best-known and also most notorious *E. coli* bacteria that produce Shiga toxin is *E. coli* O157:H7 (Barry and Dori 2000; Griffin and Tauxe 1991). Shiga toxin-producing *E. coli* cause approximately 100,000 illnesses, 3000 hospitalizations, and 90 deaths annually in the USA (Mead et al. 1999). Most reported STEC infections in the USA are caused by *E. coli* O157:H7, with an estimated 73,000 cases occurring each year (Mead et al. 1999). A study published in 2005 estimated the annual cost of *E. coli* O157:H7 illnesses to be $405 million, which included $370 million for premature deaths, $30 million for medical care, and $5 million for lost productivity (Frenzen et al. 2005).

The incubation period—that is, the time from exposure to the onset of symptoms in outbreaks of *E. coli* O157:H7 illness—is usually reported as 3–4 days, but may be as short as 1 day or as long as 10 days (Rangel et al. 2005). Infection can occur in people of all ages but is most common in children (Su and Brandt 1995). Unlike other *E. coli* pathogens, which remain on intestinal surfaces, Shiga toxin-producing bacteria, like O157:H7, are invasive (Clark M E coli food poisoning www about ecoli com). After ingestion, *E. coli* bacteria rapidly multiply in the large intestine and then bind tightly to cells in the intestinal lining (Su and Brandt 1995). This snug attachment facilitates absorption of the toxins into the small capillaries within the bowel wall (Siegler 1995; Garg et al. 2003). Once in the systemic circulation, Shiga toxin becomes attached to weak receptors on white blood cells, thus allowing the toxin to reach to the kidney where it is transferred to numerous avid (strong) receptors that hold on to the toxin (Siegler 1995). Inflammation caused by the toxins is believed to be the cause of hemorrhagic colitis, the first symptom of *E. coli* infection, which is characterized by the sudden onset of abdominal pain and severe cramps (Boyce et al. 1995). Such symptoms are typically followed within 24 h by diarrhea, sometimes fever. As the infection progresses, diarrhea becomes watery and then may become grossly bloody, that is, bloody to the naked eye (Clark M E coli food poisoning www about ecoli com). *Escherichia coli* symptoms also may include vomiting and fever, although fever is an uncommon symptom.

4.2.5 *Salmonella*

There are hundreds of different types of salmonella but not all are harmful to humans. Salmonella can cause food poisoning which can occur from poor food handling practices in home or in food outlets, seafood caught in polluted water, or eggs with dirty shells, meat, or poultry which has been contaminated by poor food handling before it gets to the food outlet, such as at the abattoir (Food Poisoning Bacteria—*Salmonella, Listeria, E. coli* 0157, *Campylobacter*. info@accepta.com). Salmonella food poisoning takes up to 48 h to develop after the food is eaten. Symptoms include nausea, stomach cramps, diarrhea, fever, and headache and may last between 3 and 21 days. It can cause death in very young, weak, or very old people. People who have cancer or are taking medication for serious health conditions such as heart, kidney, or liver problems need to also be particularly careful that they eat safe food.

4.2.6 *Listeria monocytogenes*

Listeria monocytogenes is present all around in the environment. It has also been found in low numbers in many foods. In certain foods, such as soft mold-ripened cheeses and pâtés, it may be present in higher numbers (Food Poisoning Bacteria—*Salmonella, Listeria, E. coli* 0157, *Campylobacter*. info@accepta.com). Eating foods containing high levels of *L. monocytogenes* is generally the cause of illness. *L. monocytogenes* usually causes illness in vulnerable groups such as pregnant women, babies, the elderly, and people with reduced immunity (Food Poisoning. A fact of life 2009). Among these groups, the illness is often severe and life threatening. *L. monocytogenes* is found in high-risk foods such as unpasteurized milk and dairy products, cook-chill foods, pate, meat, poultry, and salad vegetables. Signs and symptoms of food poisoning by *L. monocytogenes* range from mild, flu-like illness to meningitis, septicemia, and pneumonia. During pregnancy, it may lead to miscarriage or birth of an infected baby.

4.2.7 *Vibrio cholerae*

The *Vibrio* bacteria live in contaminated water where they are transmitted to various species of fish and seafood such as prawns, oysters, and tuna. It causes the well-known fatal disease, cholera. These bacteria are shaped like a "comma" (a punctuation symbol) with a distinctive tail and are the direct cause of cholera in humans. *Vibrio cholerae* bacteria transfer to humans via consumption of infected food or contaminated water. The majority of these bacteria are killed by stomach acid, but a few manage to survive. These remaining bacteria access the small intestine. Their aim is to invade the soft lining of the intestinal walls, but to do so they produce a type of protein that helps for growing the distinctive curly tails which used to move through the thick mucus of these walls (Food poisoning guide: *V. cholera*. www.medic8.com). Once they access these walls, they thrive and multiply. Once inside the intestinal walls, they lose their curly tails and, instead, produce a mix of proteins which are pathogenic. This means that they have the ability to cause disease and infection. These toxins are responsible for causing watery diarrhea and other symptoms (Food poisoning guide: *V. cholera*. www.medic8.com). They produce copious amounts of fluid which is expelled from the body as diarrhea and often results in serious dehydration. There is also the risk of these bacteria infecting another person due to poor sanitation or if they have contact with infected water.

V. cholera, V. parahaemolyticus bacteria form part of the *Vibrio* genus of bacteria which are known to cause food poisoning, other gastrointestinal illnesses, and blood poisoning (septicemia). Symptoms include watery diarrhea, abdominal pain, severe dehydration, vomiting, and shock (Food poisoning guide: *V. cholera*. www.medic8.com). The main risk is that of dehydration which can be fatal, so it is important that any treatment plan includes fluid replacement.

4.2.8 *Bacillus cereus*

Bacillus cereus is a type of bacteria that produces toxins. These toxins can cause two types of illness: one type characterized by diarrhea and the other, called emetic toxin, by nausea and vomiting (Food Poisoning. A fact of life 2009). These bacteria are present in foods and can multiply quickly at room temperature. *B. cereus* causes food poisoning where it is found in high-risk foods such as rice, meat, seafood, salads, potatoes, sauces, soup, and other prepared foods that have sat out too long at room temperature. Signs and symptoms are watery diarrhea, nausea, vomiting, and abdominal cramps with an incubation period of 1–6 h. This usually lasts less than 24 h after onset (Food Poisoning. A fact of life 2009).

5 Spoilage of Fruits and Vegetables

Food spoilage is not normally found on freshly collected food materials (except for some plants) but are extremely common in the environment and can cause contamination through airborne transmission. Yeast and mold are more resistant to low temperature, low pH, low water activity values, and the presence of preservatives than bacteria, and most are not heat resistant (Voysey 2007). Fungal spoilage may be characterized by highly visible, often pigmented growth, slime, off-odors, and off-flavors. Vegetables such as tomato, potato, cucumber, lettuce, as well as asparagus, carrot, and legumes are most affected by fungi (Table 1). Yeast spoilage of fresh fruits and vegetables is represented in Table 2 (Voysey

Table 1 Spoilage of fresh and stored vegetables by some genera of fungi

Vegetables affected by fungi	Genus	Type of spoilage
Most vegetables especially carrot, lettuce, celery, cabbage	*Botrytis*	Gray mold rot
Most vegetables especially carrot, lettuce, legumes, *Brassica* species	*Sclerotinia*	Watery soft rot
Legumes, carrot, *Brassica* species	*Rhizopus*	Soft rot
Tomato, cucumber, asparagus, potato	*Fusarium*	Dry rots
Tomato, potato, carrot	*Phytophthora*	Brown rots (blight)
Cucumber, legumes, potato	*Pythium*	Cottony leak
Onion, *Brassica* species	*Peronospora*	Downy mildews
Tomato, *Brassica* species	*Alternaria*	Black rots

Table 2 Yeast spoilage of fresh fruits and vegetables

Commodities	Yeast
Dates	*Saccharomyces* spp., *Candida quilliermondii*, *Hanseniaspora valbvensis*
Figs	*Candida krusei*, *Saccharomyces cerevisiae*, *Torulopsis stellata*, *Hanseniaspora valbvensis*, *Klorkera apiculata*
Strawberries	*Klorkera apiculata*
Tomatoes	*Pichia kluyveri*, *Klorkera apiculata*, *Nematospora coryli*
Legumes, coffee berries, nuts, citrus fruits	*Nematospora coryli*
Pineapple	*Candida* spp.

2007). Bacteria that cause soft rot of some fruits and most vegetables are *Erwinia* spp. and *Pseudomonas* spp. (Voysey 2007).

6 Food Preservation

Food preservation is a process involved in protection of food against microbes and other spoilage agents to permit long shelf life for future consumption. Shelf life of a food is the time during which it remains stable and retains its desired qualities (Doyle 2007). The preserved food should retain a palatable appearance, flavor, and texture, as well as its original nutritional value (Spoilage of Food. Home.pacific.nethk/ppleung/chem/preservation.htm). Basic important benefits of food preservation include the following: (1) protect food against microbes and other spoilage agents; (2) add a variety to the food and increase the food supply (examples are canned or dehydrated vegetables or other foods); (3) change raw foods into more stable form and thus increase the shelf life of foods, fruits, and vegetables to ensure safety of foods for future consumption; (4) decrease the wastage of food; (5) decrease dietary inadequacies; and (6) allow many foods to be available year-round, in great quantity and the best quality. Variety in diet is brought about with the aid of preserved food supply. For example, some Middle East countries do not grow any vegetables due to arid soil conditions (Spoilage of Food. Home.pacific.nethk/ppleung/chem/preservation.htm). This shortcoming is overcome through the import of fresh and preserved fruits and vegetables. Microorganisms, enzymes, and chemical reaction of food components are the main causes of food spoilage. So the principles of preservations are killing and inhibition of microbial growth, destroying enzymes, and retardation of chemical changes (Spoilage of Food. Home.pacific.nethk/ppleung/chem/preservation.htm).

6.1 Microbial Indicators of Product Quality

Spoilage microorganisms or their metabolic products that are present in a given food may be used as a predictive to assess the food quality and shelf life of a product. Microbial indicators that are highly correlated with food quality are represented in Table 3 (Voysey 2007). Metabolic products as indicators of a product quality include diacetyl (fruit juice concentrates), histamine (canned tuna), lactic acid (canned vegetables), trimethylamine and volatile nitrogen (seafish), and volatile fatty acids (butter). Food spoilage can be prevented by the following directives: (1) use of quality raw materials, (2) correct storage for the food type, (3) use of predictive methods, (4) hygiene of processing environment, (5) giving out appropriate shelf life, (6) usage of organic acids and antimicrobial agents, and (7) training and education.

6.2 Side Effects of Food Preservation

Principles of food preservation depend on heating up or cooking of foods such as milk, fruits, and vegetables. Heat kills microorganisms and their spores, alters protein structure, and destroys enzyme activity of microorganisms in food. Food preservation process used to inhibit microorganisms can be performed by heat treatment, smoking, irradiation, freezing, canning, meat curing, as well as salting, drying, and dehydration (Smith 2007). Some of these methods may show disadvantage such as canning where the containers that are not properly canned may result in botulism. On the other side, when foods are smoked, they absorb various chemicals from the smoke including aldehydes and acids. Aldehydes are carcinogenic, and people who eat a heavy diet of smoked foods suffer disproportionately from cancer of the mouth and stomach. Through meat curing, where strong salt solution containing $NaNO_3$, KNO_3, and spices is used, excessive intake of nitrites causes a fall in the level of hemoglobin in the blood. In long term, this leads to malnutrition and reduced lifespan. Nitrates are harmless, but when nitrates are

Table 3 Microbial indicators that are highly correlated with food quality (Voysey 2007)

Organism	Product
Acetobacter	Fresh cider
Bacillus	Bread dough
Clostridium	Hard cheeses
Pseudomonas putrefaciens	Butter
Leuconostoc mesenteroides	Sugar (during refinery)
Byssochlamys spp.	Canned fruits
Zygosaccharomyces bailii	Mayonnaise, salad dressing
Flat sour spores	Canned vegetables
Yeasts	Fruit juice concentrates
Lactic acid bacteria	Beers, wines

ingested in the diet, they are reduced to nitrites in the body. Then, nitrites may react to form nitrosamines (Sivasankar 2004). Disadvantage of freezing includes textural changes. Freezing involves the change of water contained in the food from a liquid to a solid (ice). When water freezes, it expands, and the ice crystals formed cause cell walls of food to rupture. As a result, the texture of the product will be much softer when it thaws. Textural changes are most noticeable in fruits and vegetables that have high water content and are not as apparent in products that are cooked before eating. Methods of heating include (a) blanching, usually applied before freezing of fruits and vegetables to denature enzymes; (b) pasteurization, used to destroy pathogenic microorganisms and extend the shelf life of a food; and (c) commercial sterilization, which destroys all pathogenic and toxin-forming organisms, as well as other types of organisms, which if present could grow in the food and cause spoilage under normal handling and storage conditions (Desrosier 1963). High temperatures, however, can diminish product appearance, texture, and nutrient quality of all forms of cooked food, milk sterilized by ultra-high temperature, beer, and wine (Sivasankar 2004).

7 Control Strategies of Spoilage Microorganisms

Spoilage microorganisms are not originally an essential part of foods but are widely present in water, soil, air, and other animals. Healthy living plants and animals can ward off bacteria and fungi, but as soon as they are slaughtered or harvested, their defenses deteriorate and their tissues become susceptible to spoilage microbes (Doyle 2007). The most important first step in delaying the spoilage process and that can prevent colonization by many, but not all, microbes is the good manufacturing practices with strict attention to sanitation and hygiene. Some strategies to ensure good control of microbial spoilage are discussed below (Doyle 2007):

1. Spoilage microorganisms require certain conditions for growth, and therefore management of the environment of foods can change these factors and delay spoilage. Many, but not all, microbes grow slowly or not grow at all at low temperatures, and deep refrigeration can prolong the lag phase and decrease growth rate of microbes.
2. Many microbes require a high water activity, and therefore keeping foods such as grains and cereal products dry will help to preserve them.
3. Some microbes require oxygen, while others are killed by oxygen, and some species are facultative. Managing the atmosphere during storage in packaging can retard or prevent the growth of some microbes. Several types of modified atmosphere packaging have been developed to retard growth of pathogenic and spoilage organisms (Balamatsia et al. 2006a; Charles et al. 2006; Ercolini et al. 2006; Tremonte et al. 2005).

However, due to the continuous changes of spoilage microbes, to overcome difficulties and any barriers against them, further strategies are utilized to extend shelf life of foods. Such controlling strategies must be assessed for compatibility with different foods to ensure absence of any significant organoleptic changes of foods caused by addition of preservatives (Doyle 2007).

7.1 Common Methods of Food Preservation and Processing

Preservation involves a change to the nature of a product that reduces the microbial load or limits the growth of microorganisms while maintaining the food item's nutritional value, texture, and flavor. Clean, high-quality ingredients are needed for effective preservation (Smith 2007). Use of unsound raw material is economically unwise due to the losses involved and the possible negative effect on finished product quality. The exact method of preservation used is dependent on the product, its effect on product safety, and the process facility in terms of power, space, equipment, and hygiene (Smith 2007). Food processing is often the set of methods and techniques used to transform raw ingredients into food for consumption. The *food processing industry* utilizes these processes. Food processing often takes clean, harvested, or slaughtered food components and converts them into attractive and marketable food products (Sivasankar 2004). Common methods of food preservation include canning, smoking, drying, salting, pickling, sterilization, and sugaring (Smith 2007). Some of these methods may show disadvantage as discussed above.

7.2 Common Methods of Shelf Life Extension

Shelf life extension relies on changing the storage conditions and/or the product packaging to inhibit microbial growth. Methods used for shelf life extension are freezing, chilling, vacuum packing, and controlling atmosphere packaging (Smith 2007).

7.2.1 Freezing

Freezing can be a simple process to implement and can extend the shelf life by years in some cases. Product quality is retained better by faster freezing speeds to avoid the smaller size of ice crystals formed. Numerous methods are available for freezing product, including blast freezing (cabinet, room, or spiral freezer, dependent on throughput), plate freezing (for blocks of meat, fish, or vegetables), or scraped surface heat exchangers for ice cream (Smith 2007). The exact method will depend on throughput and costs, e.g., a liquid nitrogen bath uses an expensive coolant but has a very high throughput and takes up less space than a tunnel.

7.2.2 Chilling

Chilling is done via a blast chiller cabinet or room; larger-scale production can use spiral chillers for continuous production. Liquids can be cooled using plate or scraped surface heat exchangers (Smith 2007).

7.2.3 Vacuum Packing

Vacuum removes oxygen (when reacts with food causing undesirable changes in color and flavor). Vacuum packing is relatively a simple way of extending shelf life, with refrigeration. It is often used for meat or fish products (Smith 2007). Use of contaminated material, however, can lead to growth of pathogenic anaerobic bacteria. This method does have risks, especially in leaky seals or damaged packaging. If there is contamination, the spoilage may not be readily visible.

7.2.4 Controlled Atmosphere Packaging

Controlled atmosphere packaging is used as a means of extending the shelf life of products such as chilled meat, fish, dairy, or poultry (Smith 2007). The atmosphere inside the packaging is modified or controlled to inhibit or reduce the rate of spoilage. This is an expensive process due to the heavy gauge packaging needed, the machinery setup required, and the food grade gas mix used (Smith 2007). A less aggressive version is gas flushing that has lower machinery costs but a lower throughput. These systems are used with careful temperature control (refrigeration).

8 Recent Advance in Food Preservation

Recent processing technologies, in addition to the thermal processing, being developed to kill spoilage microbes, are discussed below.

8.1 Irradiation

Some of the future methods of food preservation are irradiation and chemical additives. Although these methods are currently in use, they are expected to expand and develop further. Irradiation of food is the process of exposing food to ionizing radiation (Blum 2012). This process can alter the bacteria, microorganism, or virus' DNA, without harming the food. Irradiation is attractive because of its selective targeting. It is already used on non-food items. The molecular bonds in the microbial DNA are the main targets of the irradiation, but DNA and RNA synthesis, denaturation of enzymes, and cell membrane alterations may also be affected (Blum 2012). The process of irradiation opens the possibility to process a large number of foods in great quantities; however, it can be expensive. The buildings for such a process require specific infrastructure and construction that is both expensive and time-consuming. The Food and Agriculture Organization, the International Atomic Energy Agency, and the World Health Organization concluded in their report that any food irradiated up to a maximum dose of 10 kGy is considered safe and healthy (Blum 2012). Essentially, three things were concluded in their report: (1) It will not lead to toxicological changes in the food that will negatively affect our health. (2) The technology will not increase the microbial risk of the consumer. (3) Irradiation will not lead to nutritional losses. However, most consumers are still radiation phobic despite these positive results. They are not willing to buy something that has, in their mind, been radiated (Blum 2012). Irradiation of fruit and meat is reported (Balamatsia et al. 2006b; Fan et al. 2006; Mahapatra et al. 2005).

8.2 Addition of Chemicals

Addition of chemicals is another process to preserve foods. Some familiar examples of food additives are sodium benzoate, benzoic acid, calcium, sodium propionate, propionic acid, calcium, potassium, and sodium sorbate, sorbic acid, and sodium and potassium sulfite. Consumers feel that this is a risk because of the unnatural state of chemicals. Chemicals are added to prevent spreading of mold or other microorganisms. Furthermore, addition of oxygen-scavenging chemicals (oxygen eliminators) is an effective preservative method because oxygen increases the possibility of spoilage to the food (Blum 2012). A special class of additives that reduce oxidation is known as the sequestrant, that is, compounds that capture metallic ions, such as those of copper, iron, and nickel, and remove them from contact with foods (World of Microbiology and Immunology 2003). The removal of these ions helps preserve foods because in their free state, they increase the rate at which oxidation of foods takes place. Some examples of sequestrants used as food preservatives are ethylenediaminetetraacetic acid, citric acid, sorbitol, and tartaric acid.

8.3 Antimicrobials

Recently, naturally occurring antimicrobials including chitosan, lysozyme, and nisin; various plant extracts such as tea, spices, and their essential oils; as well as phenolic compounds have been widely investigated and are recommended for food preservation (Rawdkuen et al. 2012). Food-borne illnesses that result from consuming food contaminated with pathogenic bacteria have been of serious public concern worldwide. Food-borne illnesses associated with *E. coli* 0157:H7, *S. aureus*, *Salmonella enteritidis*, and *L. monocytogenes* are a major public health concern all over the world (Juneja et al. 2012). These bacteria are correlated with serious illnesses such as urinary tract infection, cholecystitis, or septicemia, post-operative wound infections, toxic shock syndrome, endocarditis, osteomyelitis, and food poisoning. Consumer demand for naturally derived compounds such as anti-microbial substances has been increased (Rawdkuen et al. 2012; Yousef 2013). Antimicrobial substances have been used to inhibit food-borne bacteria and extend the shelf life of processed food by either reducing the microbial growth rate or by extending the lag phase of the target microbes. Bacteriocin, including nisin, can help control spoilage bacteria in dairy products, fish, juice, and vegetables (Mahapatra et al. 2005; Cha and Chinnan 2003; Deegan et al. 2006; Jamuna et al. 2005). Chitosan incorporated into foods or used as a coating for fruits and vegetables inhibits growth of some spoilage bacteria and yeasts (Altieri et al. 2005; Devlieghere et al. 2004). Many herbs, essential oils, and spices have demonstrated potential inhibitory activity against spoilage microbes in a variety of foods (Arici et al. 2005; Angelini et al. 2006; Kang et al. 2006; Matan et al. 2006; Oussalah et al. 2006; Sacchetti et al. 2005; Kaur et al. 2013).

8.4 High-Pressure Preservation

The most recent technology and safe process of food preservation is the high-pressure preservation. Balasubramaniam et al. (Balasubramaniam et al. 2008; Yousef and Balasubramaniam 2013) developed a process where food is attacked with 100,000 pounds per square inch of pressure. A process in which high-pressure processing works for food preservation was explained. The food is packaged in a plastic bag and then put into the first compartment. That compartment is also filled with water, to help with the pressure. The second compartment is filled with hydraulic fluid, which is used to press the piston between the two compartments. The water becomes more condensed, and as a result the pressure in the first compartment increases rapidly (Freedman 2011). After only a few minutes, any food can be ready to eat. In this process, no chemicals are added; there is no contamination or taste alteration to the food. The bacteria in the food remain intact; however, they die due to the pressure-induced dismantlement of their DNA structure. This process destroyed pathogens and spoilage organisms while keeping food chemistry basically intact. High-pressure technology enables pasteurization of foods with minimal effects on taste, texture, appearance, or nutritional value (Balasubramaniam et al. 2008; Yousef and Balasubramaniam 2013). Almost all foods are able to be pressurized in the machine. The only exception is some veggies and fruits, which get too crushed (Freedman 2011). This technology is so new, simple, and so good to reserve for large industrial food processing plants. High-pressure processing of fruits, juices, meat, and fish is reported (Hocking et al. 2006; Tahiri et al. 2006; Torres and Velazquez 2005).

9 Conclusion

Because evidence exists that microorganisms can acquire varying levels of resistance or tolerance to environmental stresses, there is some concern that this might provide protection for food-borne pathogens against antimicrobials and preservation processes. Development of resistance to manufacturing and processing treatments could occur in a food production system and could influence preservation treatment efficacy. Food preservation processes are designed to either inhibit the growth of or inactivate bacteria, depending upon the type and severity of the process used. Thus, food preservation exposes bacteria to a lethal stresses. Food preservation has become vital, and preservation has come from simple processes such as salting to more complex preserving methods such as irradiation and chemical additives. Looking into the future, high-pressure preservation seems to be the next logical step. In an increasingly health-conscious world, uncontaminated, well-preserved food source and low costs of production are the ultimate goals to ensure and enjoy a preservative food.

References

Altieri C, Scrocco C, Sinigaglia M, Del Nobile M (2005) Use of chitosan to prolong mozzarella cheese shelf life. J Dairy Sci 88:2683–2688

Angelini P, Pagiotti R, Menghini A, Vianelli B (2006) Antimicrobial activities of various essential oils against foodborne pathogenic or spoilage moulds. Ann Microbiol 56:65–69

Arici M, Sagdic O, Gecgel U (2005) Antibacterial effect of Turkish black cumin (*Nigella sativa* L.) oils. Grasas Y Aceites 56:259–262

Australian Government (2010) Food poisoning and contamination. Department of Health. www.health.gov.au

Baixas-Nogueras S, Bover-Cid S, Veciana-Nogues MT, Marine-Font A, Vidal-Carou MC (2005) Biogenic amine index for freshness evaluation in iced Mediterranean hake (*Merluccius merluccius*). J Food Prot 68:2433–2438

Balamatsia C, Paleologos E, Kontominas M, Savvaidis I (2006a) Correlation between microbial flora, sensory changes and biogenic amines formation in fresh chicken meat stored aerobically or under modified atmosphere packaging at 4°C: possible role of biogenic amines as spoilage indicators. Int J Gen Mol Microbiol 89:9–17

Balamatsia C, Rogga K, Badeka A, Kontominas M, Savvaidis I (2006b) Effect of low-dose radiation on microbiological, chemical, and sensory characteristics of chicken meat stored aerobically at 4°C. J Food Prot 69:1126–1133

Balasubramaniam VM, Farkas D, Turek E (2008) Preserving foods through high-pressure processing. Food Technol 62(11):32–38

Barry E, Dori Z (2000) Enterobacteriaceae. In Mandell, Douglas, and Bennett's Principles and practice of infectious diseases, 5th edn, Chap. 206, pp 2294–2310

Blum D (2012) Food that lasts forever. TIME Magazine, 12 Mar 2012. Print

Bota G, Harrington P (2006) Direct detection of trimethylamine in meat food products using ion mobility spectrometry. Talanta 68:629–635

Boyce TG et al (1995) *Escherichia coli* O157:H7 and the hemolytic-uremic syndrome. N Engl J Med 333:364–368

Casey G, Dobson A (2003) Molecular detection of *Candida krusei* contamination in fruit juice using the *citrate synthase* gene cs1 and a potential role for this gene in the adaptive response to acetic acid. J Appl Microbiol 95:13–22

Castro M, Garro O, Gerschenson L, Campos C (2003) Interaction between potassium sorbate, oil and Tween 20: its effect on the growth and inhibition of *Z. bailii* in model salad dressings. J Food Safety 23:47–59

Cha D, Chinnan M (2003) Emerging role of nisin in food and packaging systems. Food Sci Biotechnol 12:206–212

Chang S, Kang D (2004) *Alicyclobacillus* spp. in the fruit juice industry: history, characteristics, and current isolation/detection procedures. Crit Rev Microbiol 30:55–74

Charles N, Williams S, Rodrick G (2006) Effects of packaging systems on the natural microflora and acceptability of chicken breast meat. Poult Sci 85:1798–1801

Clark M. *E. coli* food poisoning. www.about-ecoli.com

Couto J, Neves F, Campos F, Hogg T (2005) Thermal inactivation of the wine spoilage yeasts *Dekkera/Brettanomyces*. Int J Food Microbiol 104:337–344

Deegan L, Cotter P, Hill C, Ross P (2006) Bacteriocins: biological tools for bio-preservation and shelf-life extension. Int Dairy J 16:1058–1071

Desrosier NW (1963) The technology of food preservation. AVI Publications, Westport, Conn

Devlieghere F, Vermeulen A, Debevere J (2004) Chitosan: antimicrobial activity, interactions with food components and applicability as a coating on fruit and vegetables. Food Microbiol 21:703–714

Doyle M (2007) Microbial food spoilage: losses and control strategies. Food Research Institute, University of Wisconsin–Madison, Madison, WI, pp 1–16

Ellis DI, Goodacre R (2006) Quantitative detection and identification methods for microbial spoilage. In: Balakburn CW (ed) Food spoilage microorganisms. CRC Press LLC, Boca Raton, FL, pp 3–27

Ellis DI, Broadhurst D, Goodacre R (2004) Rapid and quantitative detection of the microbial spoilage of beef by Fourier transform infrared spectroscopy and machine learning. Anal Chim Acta 514:193–201

Ercolini D, Russo F, Torrieri E, Masi P, Villani F (2006) Changes in the spoilage-related microbiota of beef during refrigerated storage under different packaging conditions. Appl Environ Microbiol 72:4663–4671

Fan X, Annous B, Sokorai K, Burke A, Mattheis J (2006) Combination of hot-water surface pasteurization of whole fruit and low-dose gamma irradiation of fresh-cut cantaloupe. J Food Prot 69:912–919

Feng P, Stephen D, Mechail A, William B (2002) Enumeration of *Escherichia coli* and the coliform bacteria. In Bacteriological analytical manual, 8th edn

Fitzgerald D, Stratford M, Gasson M, Narbad A (2004) The potential application of vanillin in preventing yeast spoilage of soft drinks and fruit juices. J Food Prot 67:391–395

Food Poisoning. A fact of life (2009). www.nutrition.org.uk, www.foodafactoflife.org.uk

Freedman DH (2011) The bright, Hi-Tech future of food preservation. Discover Magazine, Sept 2011

Frenzen P, Drake A, Anqulo F (2005) Economic cost of illness due to *E. coli* O157 infections in the United States. J Food Prot 68:2623–2630

Garg A, Suri R, Barrowman N, Rehman F, Matsell D, Rosas M, Salvadori M, Haynes R, Clark W (2003) Long-term renal prognosis of diarrhea-associated hemolytic uremic syndrome: a systematic review, meta-analysis, and meta-regression. J Am Med Assoc 290:1360

Gram L, Ravn L, Rasch M, Bruhn JB, Christensen AB, Givskov M (2002) Food spoilage: interactions between food spoilage bacteria. Int J Food Microbiol 78:79–97

Griffin P, Tauxe R (1991) The epidemiology of infections caused by *E. coli* O157:H7, other enterohemorrhagic *E. coli*, and the associated hemolytic uremic syndrome. Epidem Rev 13:60–98

Harris RS, Von Lesecke H (1973) Nutritional evaluation of food processing. Avi Publishing, Westport, Conn

Hocking AD, Begum M, Stewart CM (2006) Inactivation of fruit spoilage yeasts and moulds using high pressure processing. Adv Exp Med Biol 571:239–246

Innocente N, Biasutti M, Padovese M, Moret S (2007) Determination of biogenic amines in cheese using HPLC technique and direct derivatization of acid extract. Food Chem 101:1285–1289

James M (2000) Modern food microbiology at 21, 6th edn. Aspen Publishers, Gaithersburg, MD

Jamuna M, Babusha S, Jeevaratnam K (2005) Inhibitory efficacy of nisin and bacteriocins from *Lactobacillus* isolates against food spoilage and pathogenic organisms in model and food systems. Food Microbiol 22:449–454

Juneja VK, Dwivedi HP, Yan X (2012) Novel natural food antimicrobials. Annu Rev Food Sci Technol 3:381–403

Kang P, Park K, Eun J, Oh S (2006) Antimicrobial effect of roselle (*Hibiscus sabdariffa* L.) petal extracts on food-borne microorganisms. Food Sci Biotechnol 15:260–263

Kantor LS, Upton K, Manchester A, Oliveira V (1997) Estimating and addressing America's food losses. Food Rev 20:2–12

Kaur J, Kaur S, Mahajan A (2013) Herbal medicines: possible risks and benefits. Am J Phytomed Clin Ther 2:226–239

Lin MS, Al-Holy M, Chang SS, Huang YQ, Cavinato AG, Kang DH, Rasco BA (2005) Rapid discrimination of *Alicyclobacillus* strains in apple juice by Fourier transform infrared spectroscopy. Int J Food Microbiol 105:369–376

Loureiro V, Malfeito-Ferreira M (2003) Spoilage yeasts in the wine industry. Int J Food Microbiol 86:23–50

Mahapatra A, Muthukumarappan K, Julson J (2005) Applications of ozone, bacteriocins and irradiation in food processing: a review. Crit Rev Food Sci Nutr 45:447–461

Martorell P, Stratford M, Steels H, Fernandez-Espinar MT, Querol A (2007) Physiological characterization of spoilage strains of *Zygosaccharomyces bailii* and *Zygosaccharomyces rouxii* isolated from high sugar environments. Int J Food Microbiol 114:234–242

Matan N, Rimkeeree H, Mawson AJ, Chompreeda P, Haruthaithanasan V, Parker M (2006) Antimicrobial activity of cinnamon and clove oils under modified atmosphere conditions. Int J Food Microbiol 107:180–185

Mead PM et al (1999) Food-related illness and death in the United States. Emerg Infect Dis 5: 607–625

Meyer R, Grant M, Luedecke L, Leung H (1989) Effects of pH and water activity on microbiological stability of salad dressing. J Food Prot 52:477–479

Oussalah M, Caillet S, Saucier L, Lacroix M (2006) Antimicrobial effects of selected plant essential oils on the growth of a *Pseudomonas putida* strain isolated from meat. Meat Sci 73: 236–244

Pepe O, Blaiotta G, Moschetti G, Greco T, Villani F (2003) Rope-producing strains of *Bacillus* spp. from wheat bread and strategy for their control by lactic acid bacteria. Appl Environ Microbiol 69:2321–2329

Pitt J, Hocking A (1997) Fungi and food spoilage. Blackie Academic and Professional, New York

Rangel J, Phyllis H, Collen C, Griffin P, David L (2005) Epidemiology of *E. coli* O157:H7 outbreaks, United States, 1982-2002. Emerg Inf Dis 11:603

Rasch M, Andersen J, Nielsen K, Flodgaard L, Christensen H, Givskov M, Gram L (2005) Involvement of bacterial quorum-sensing signals in spoilage of bean sprouts. Appl Environ Microbiol 71:3321–3330

Rawdkuen S, Phunsiri S, Damrongpol K, Benjakul S (2012) Antimicrobial activity of some potential active compounds against food spoilage microorganisms. Afr J Biotechnol 11:13914–13921

Restuccia C, Randazzo C, Caggia C (2006) Influence of packaging on spoilage yeast population in minimally processed orange slices. Int J Food Microbiol 109:146–150

Sacchetti G, Maietti S, Muzzoli M, Scaglianti M, Manfredini S, Radice M, Bruni R (2005) Comparative evaluation of 11 essential oils of different origin as functional antioxidants, antiradicals and antimicrobials in foods. Food Chem 91:621–632

Sherratt TN, Wilkinson DM, Bain RS (2006) Why fruits rot, seeds mold and meat spoils: a reappraisal. Ecol Model 192:618–626

Siegler R (1995) The hemolytic uremic syndrome. Pediatr Nepharol 42:1505

Siegmund B, Pollinger-Zierler B (2006) Odor thresholds of microbially induced off-flavor compounds in apple juice. J Agric Food Chem 54:5984–5989

Sivasankar B (2004) Food processing and preservation. Prentice-Hall of India, New Delhi

Smith DA (2007) Food preservation, safety, and shelf life extension. University of Nebraska-Lincoln Extension, Institute of Agriculture Natural Resources, Lincoln, NE

Smits G, Brul S (2005) Stress tolerance in fungi—to kill a spoilage yeast. Curr Opin Biotechn 16: 225–230

Su C, Brandt L (1995) *E. coli* O157:H7 infection in humans. Ann Internal Med 123: 698–707

Tahiri I, Makhlouf J, Paquin P, Fliss I (2006) Inactivation of food spoilage bacteria and *E. coli* O157:H7 in phosphate buffer and orange juice using dynamic high pressure. Food Res Int 39:98–105

Torres JA, Velazquez G (2005) Commercial opportunities and research challenges in the high pressure processing of foods. J Food Eng 67:95–112

Tremonte P, Sorrentino E, Succi M, Reale A, Maiorano G, Coppola R (2005) Shelf life of fresh sausages stored under modified atmospheres. J Food Prot 68:2686–2692

Voysey P (2007) Microbiological risk assessment. Campden & Chorleywood Food Research Association. http://www.food.gov.uk

World of Microbiology and Immunology (2003) http://www.encyclopedia.com/topic/food_preservation.aspx

Yousef A (2013) Natural antimicrobial peptides for food applications and beyond. Food Science and Technology. Ohio State University, Columbus, OH

Yousef AE, Balasubramaniam VM (2013) Physical methods of preservation. In: Doyle MP, Buchanan RL (eds) Food microbiology: fundamentals and frontiers, 4th edn. ASM Press, Washington, DC