Chapter 2
Overview of Microbial Contamination of Foods and Associated Risk Factors

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Abstract Microorganisms like molds, yeasts, bacteria, and viruses can cause food spoilage and foodborne diseases. For the past decade, the increase in foodborne infections has become an important public health concern worldwide. According to a report of the World Health Organization, hundreds of millions of people worldwide suffer from diseases caused by contaminated food. In order to ensure the protection of consumers from detrimental impacts of food microbiological contamination, it is important to improve the understanding and awareness of the sources and to identify the routes of transmission of pathogens into foods. This chapter thus addresses the microbiological contamination of foods including the mechanisms of microbiological contamination, microbial contaminants, and their commonly associated foods. In addition, it discusses the impacts of microbial contaminations and their risk factors associated with foodborne diseases.

Keywords Food microbiology · Microorganism · Microbial contamination · Foodborne disease · Food pathogen · Microbial toxin · Microbial growth factor · Food spoilage · Toxicoinfection · Food safety hazard · Risk factor · Food security · Food hygiene · Safe food processing

1 Introduction

Food is defined as edible substances, usually of plant or animal origin, consisting of nourishing and nutritive components, such as carbohydrates, fats, proteins, essential minerals, and vitamins. When ingested and assimilated through digestion, they sustain life, generate energy, and provide growth, maintenance, and health [1]. Food also meets emotional, social, and psychological needs. Despite their beneficial roles in the body, foods can also serve as vehicles for disease transmission and cause of death if contaminated with harmful microorganisms, microbial toxins, or

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environmental contaminants, such as chemical allergens and microphysical particles [2]. For the past decade, the increase in foodborne infections has become a global public health concern [3]. Microorganisms play an important role in food poisoning. There are many types of microorganisms of different forms and complex structures. Bacteria, molds, yeasts, and viruses have a greater impact on food deterioration [4].

Food contaminated by pathogens is a serious issue, as it can lead to a wide range of health problems. Foodborne illnesses can be fatal and may cause suffering, discomfort, and debilitation among the survivors. Pathogens are responsible for more than 200 diseases, including typhoid fever, diarrhea, and cancer [5] and can lead to the death of unsuspecting consumers in both developing and developed countries [6]. In the United States, between 1972 and 1978, among the total number of cases reported of foodborne disease outbreaks, pathogenic microorganisms caused 94.4%, and only 1.1% and 4.3% were caused by parasites and chemicals, respectively. At present, the occurrence of foodborne diseases caused by pathogenic microorganisms far exceeded compared to all other contamination combined. The consumption of pathogen-contaminated foods also creates an economic impact that can be devastating to the consumers, the nation, food dealers, and food companies.

The microbiological aspect of food safety involves exclusion of pathogenic microorganisms or microbial toxins from food, which can pose potential health hazards by their presence in food items. This implies the prevention and management of microbiological contamination of foods [7]. There are different ways foods can be contaminated in preproduction, production, and post-production stages. Hence, reliable and safe food supply needs to be free from harmful contaminants, and it is highly essential for the general health and daily life, economic development, and social stability [2, 8]. This chapter addresses different aspects of microbial contamination of foods including sources and health impacts of microbial contaminants. The information can help researchers, policy makers, industries, and consumers to take measures to early detect and eliminate sources of microbial contaminations and to prevent health issues and economic losses caused by microbial food contamination.

2 Types of Microbial Contaminants in Foods

The microbial groups responsible for causing foodborne diseases and food spoilage consist of several types of bacteria, yeasts, molds, and viruses. Among them, bacteria constitute the largest group because of their prevalent presence and rapid growth rate when all nutrients are available in the foods; they can grow even under conditions where yeasts and molds cannot grow. As a result, they are considered the most detrimental in food contaminations [2].

2.1 Bacteria

Among all types of microorganisms that contaminate foods, bacteria make up the most important group due to their diversity and actions of greater frequency. In the presence of favorable conditions, bacteria are capable of quickly multiplying on the foods, by causing alterations in foods and sometimes cause intoxications [4]. Bacteria are unicellular organisms that exist in various forms. The most common forms are spherical (cocci), rod-shaped (bacilli), and curved (spirilla) [9]. Regarding reproduction, bacteria reproduce by binary fission, which is the division of the cell into two equal parts. In certain situations, some bacteria (*Clostridium, Bacillus*) can form highly resistant structures to temperatures. These structures are called endospores, which are formed when the cells are in the presence of unfavorable growing conditions (i.e., lack of nutrients). Once the endospores encounter favorable growing conditions, they can germinate and form cells identical to the originated ones [4].

A wide range of bacterial genera are accountable for food spoilage and foodborne diseases, which include *Citrobacter*, *Escherichia*, *Enterobacter*, *Proteus*, *Salmonella*, *Shigella*, *Yersinia*, *Vibrio*, *Aeromonas*, *Plesiomonas*, *Pseudomonas*, *Acetobacter, Acinetobacter, Morexella, Flavobacterium, Alcaligenes, Psychrobacter, Micrococcus, Staphylococcus, Streptococcus, Enterococcus, Bacillus, Sporolactobacillus, Clostridium,* and *Listeria*. On the contrary, there are good bacterial genrea that are used in food industries as biopreservatives (*Lactococcus*, *Lactobacillus*), probiotics (*Lactobacillus*), and food bioprocessing (*Lactococcus*, *Lactobacillus*). A brief description of few important bacterial genera that are responsible for most of the foodborne diseases is given in Table 2.1.

2.2 Yeast and Mold

Although they present very different features, molds and yeasts belong to the same taxonomical group—fungi [4]. The large and diverse group of microscopic foodborne yeasts and molds includes several hundreds of species. The ability of these organisms to attack many foods is due to their relatively versatile environmental requirements. Although the majority of yeasts and molds are obligate aerobes (require free oxygen for growth), their acid/alkaline requirements (pH2–9) and temperature requirements (−8 to 45 °C) for growth are quite broad, with a few species capable to grow below or above this range. Moisture requirements of foodborne molds are relatively low; most species can grow at a water activity (a_w) of 0.85 or less, although yeasts generally require a higher water activity [10].

Both yeasts and molds cause various degrees of deterioration and decomposition of foods. Their detectability in or on foods depends on food type, organisms involved, and degree of invasion. The contaminated food may be slightly blemished, severely blemished, or completely decomposed. Abnormal flavors and odors may also be produced. Several foodborne molds, and possibly yeasts, may also be

Table 2.1 Important bacterial genera responsible for food spoilage and foodborne diseases [2, 4, 9]

Name of the genus	Shape	Size (μm)	Important species	Possible source/location	Relation with temperature
Citrobacter.	Straight rod	1 × 4	*Citrobacter freundii*	Found in the intestinal contents of humans, animals, birds, and in the environment	Mesophiles
Escherichia.	Straight rod	1 × 4	*Escherichia coli*	Found in the intestinal contents of humans, warm-blooded animals, and birds	Mesophiles
Enterobacter.	Straight rod	1 × 2	*Enterobacter aerogenes*	Found in the intestinal contents of humans, animals, birds, and in the environment	Mesophiles
Proteus.	Straight rod	0.5 × 1.5	*Proteus vulgaris*	Found in the intestinal contents of humans and animals and the environment.	–
Salmonella.	Medium rod	1 × 4	*Salmonella enterica* ssp. *enterica*	Found in the intestinal contents of humans, animals, birds, and insects	Mesophiles
Shigella.	Medium rod	–	*Shigella dysenteriae*	Found in the intestine of humans and primates	Mesophiles
Yersinia.	Small rod	0.5 × 1	*Yersinia enterocolitica*	Present in the intestinal contents of animals	–
Vibrio.	Curved rod	0.5 × 1	*Vibrio cholerae, Vib. parahaemolyticus, Vib. vulnificus, Vib. alginolyticus*	Found in freshwater and marine environments	Mesophiles
Aeromonas.	Small rod	0.5 × 1	*Aeromonas hydrophila*	Found in water environment	Psychrotrophs
Plesiomonas.	Small rod	0.5 × 1	*Plesiomonas shigelloides*	Found in fish and aquatic animals	–
Pseudomonas.	Straight/ curved rod	0.5 × 5	*Pseudomonas fluorescens, Pse. Aeruginosa, Pse. Putida.*	Found widely in the environment	Psychrotrophs
Acetobacter.	Ellipsoid to rod	0.6 × 4	*Acetobacter aceti*	Widely distributed in plants and in places where alcohol fermentation occurs	Mesophiles
Acinetobacter.	Rod	1 × 2	*Acinetobacter calcoaceticus*	Found in soil, water, and sewage	Mesophiles

Name of the genus	Shape	Size (μm)	Important species	Possible source/location	Relation with temperature
Morexella.	Short rod	1 × 1.5	*Morexella lacunata*	Found in the mucous membrane of animals and humans	Mesophiles
Flavobacterium.	Rod	0.5 × 3	*Flavobacterium aquatile*	Found in soil and fresh water in a variety of environments-	Psychrotrophs
Alcaligenes.	Rods/ coccobacilli	0.5 × 1	*Alcaligenes faecalis*	Present in water, soil, or fecal material	Mesophiles
Psychrobacter.	Coccobacilli	1 × 1.5	*Psychrobacter immobilis*	Found in fish, meat, and poultry products	Psychrotrophs
Micrococcus.	Spherical	0.2–2	*Micrococcus luteus*	Found in mammalian skin	Mesophiles
Staphylococcus.	Spherical	0.5–1	*Staphylococcus aureus*	Present in the skin of humans, animals, and birds	Mesophiles
Streptococcus.	Spherical/ ovoid	1	*Streptococcus pyogenes*	Present as commensals in the human respiratory tract	Mesophiles
Enterococcus.	Spherical	1	*Enterococcus faecalis*	Found in intestinal contents of humans, animals, and birds, and the environment	Mesophiles
Bacillus.	Rod	0.5–1 × 2–10	*Bacillus cereus, bac. Coagulans, bac. Stearothermophilus*	Present in soil, dust, and plant products (especially spices)	Mesophiles
Sporolactobacillus.	Medium rod	1 × 4	*Sporolactobacillus inulinus*	Found in chicken feed and soil	–
Clostridium.	Rod	–	*Clo. Tyrobutyricum, Clo. Saccharolyticum, Clo. Laramie*	Found in soil, marine sediments, sewage, decaying vegetation, and animal and plant products	Mesophiles / Psychrotrophs
Listeria	Short rod	0.5 × 1	*Listeria monocytogenes*	Widely distributed in the environment and have been isolated from different types of foods	Psychrotrophs

hazardous to human or animal health because of their ability to produce toxic metabolites known as mycotoxins. Most mycotoxins are stable compounds that are not destroyed during food processing or home cooking. Although the generating organisms may not survive food preparation, the preformed toxin may still be present [10].

There are wide ranges of molds that are associated with spoiled fruits and vegetables (e.g., *Aspergillus*, *Alternaria*, and *Rhizopus*), dairy products (e.g., *Alternaria*), grains (e.g., *Penicillium*), meats (e.g., *Penicillium*), and bread (e.g., *Penicillium*). Few molds are also used as food additives (e.g., *Asp. Oryzae., Asp. Niger.*) and food-processing aid (e.g., *Mucor rouxii*) [2].

Yeasts are important in food because of their ability to cause spoilage. Many are also used in food bioprocessing. Some are used to produce food additives [2, 11]. *Saccharomyces* form pellicles in beer, wine, and brine to cause spoilage. *Saccharomyces cerevisiae* variants are also used in baking for leavening bread and in alcoholic fermentation. *Rhodotorula* are pigment-forming yeasts and can cause discoloration of foods such as meat, fish, and sauerkraut (e.g. *Rhodotorula glutinis*). *Torulopsis* cause spoilage of milk because they can ferment lactose (e.g., *Torulopsis versatilis*). They also spoil fruit juice concentrates and acid foods. *Candida* spoils foods with high acid, salt, and sugar and forms pellicles on the surface of liquids (e.g., *Candida lipolyticum*). *Zygosaccharomyces* cause spoilage of high-acid foods, such as sauces, ketchups, pickles, mustards, mayonnaise, and salad dressings, especially those with less acid and less salt and sugar (e.g., *Zygosaccharomyces bailii*).

2.3 Virus

Viruses are regarded as noncellular entities. Bacterial viruses (bacteriophages) are important in food microbiology and are widely available in nature [12, 13]. Unlike bacteria, yeasts, and molds, viruses are incapable of reproducing independently. Instead, they must first invade the cells of another living organism called the host before they can be multiplied [14]. Viruses are composed of nucleic acids (DNA or RNA) and several proteins. A bacteriophage attaches itself to the surface of a host bacterial cell and inoculates its nucleic acid into the host cell. Subsequently, many phages form inside a host cell and are released outside followed by lysis of a cell [2]. Bacteriophage infections of starter cultures of lactic or other fermentative bacteria can interfere seriously with the manufacture of cheese, buttermilk, sauerkraut, pickles, wine, beer, and other desirable fermentative products [15]. On the other hand, virus-borne diseases can be transmitted by food to human beings. Although viruses require a live host cell and cannot multiply in foods, they can remain viable and infectious for long periods, even under highly adverse conditions, such as drying, freezing, and pasteurization.

Several pathogenic viruses have been identified as causing foodborne diseases in humans. Hepatitis A and Norwalk-like viruses have been implicated in foodborne outbreaks. Several other enteric viruses, such as poliovirus, echo-virus, and coxsackievirus, can cause foodborne diseases [2]. Heating a product to an internal temperature of at least 72°C is considered adequate to inactivate both these viruses [16].

3 Sources of Microbial Contamination

Alarmingly, pathogenic microbes can potentially be found more or less everywhere. Some of them are sustained in humans and contaminate food supply via the excreta of infected humans, while many others are sustained in animals. Some persist in the environment or multiple hosts and contaminate foods via pathways that reflect the variety of ecosystems that make up our food supply [7]. Food safety depends on understanding these pathways or mechanisms well enough to prevent them. The different mechanisms or pathways through which pathogenic microorganisms or microbial toxins get into foods are briefly discussed subsequently.

3.1 Preharvest Factors

While being grown in the field, plant foods can be contaminated with microorganisms through water used for irrigation, application of pesticides, manure applied as fertilizer, migratory or wild animals, and practices of workers in the field [7].

3.1.1 Irrigation Water

The inside tissue of foods from plant sources is essentially sterile, except for a few porous vegetables (e.g., radishes and onions) and leafy vegetables (e.g., cabbage and Brussels sprouts) [2]. Contaminated water used for irrigation has been suspected as the likely cause of contamination of lettuce and tomatoes with *E. coli* 0157:H7 and mangoes with *Salmonella* [7]. A study conducted on crops (lettuce, carrots, and amaranthus) demonstrated that the crops got contaminated with *Salmonella*, *Vibrio* spp. and *E. coli* due to the presence of these pathogens in irrigation water [17]. Researchers have also demonstrated that the method of application of irrigation water directly influences food contamination with microorganisms during harvest [18].

3.1.2 Manure Applied as Fertilizer

Many types of molds, yeasts, and bacterial genera (e.g., *Enterobacter, Pseudomonas, Proteus, Micrococcus, Enterococcus, Bacillus,* and *Clostridium*) can enter into foods from the soil [2]. This microbial contamination can be amplified when untreated sewage and manure are applied as plant fertilizers with improper application time or improper composting [19]. Soil contaminated with fecal materials can be a source of enteric pathogenic bacteria and viruses in food [2]. A number of studies have demonstrated the long-term survival of *E. coli* 0157:H7 and *Salmonella* in manure [17, 20].

3.2 Harvest Factors

A wide variety of equipment used in harvesting can be easily contaminated by many types of pathogenic microorganisms from air, raw foods, water, and personnel getting into the equipment. Microorganisms including pathogens can be built up in improperly washed and sanitized harvesting equipment, such as knives, chippers, and containers including trailers, boxes, bins, and truck beds. Depending on moisture, nutrients, temperature, and exposure time, microorganisms can be multiplied in harvesting equipment from a low initial population to a high level and contaminate large volumes of foods [2]. Microbial contamination of plant products can also occur through the contaminated unwashed hands of the field workers at the time of harvesting [7].

3.3 Preslaughter and Slaughter Contamination Factors

Livestock may be colonized by potentially pathogenic microorganisms prior to slaughter, and if care is not taken during the procedures of handling, transporting, slaughtering, and dressing livestock, the edible portions of the meat carcass surface can be contaminated with organisms (e.g., *Salmonella spp*. and *E.coli* (EHEC)) capable of causing foodborne illness in humans [21]. For meat and poultry products, studies showed that many potential human pathogens colonize their animal hosts without causing clinical signs, making it difficult to detect carriers [22]. In apparently healthy livestock going to slaughter, pathogenic microorganisms are confined primarily to the gastrointestinal tract and exterior surfaces, such as the hooves, hide and skin, hair, or fleece [21, 23], while internal organs and intact internal muscle are free of microorganisms. Poultry farms with a large population of birds are a potential source, where microbial pathogenic contaminants can be spread rapidly [24]. In the case of poultry, the feeding of infected foodstuffs can result in large numbers of chickens and their eggs carrying food-poisoning bacteria [19]. Drinking water, rodents, insects, dogs, cats, human stools, farm equipment, footwear, and work clothes of handlers are other potential sources to infect poultry flocks [7]. When care is not taken in removing animal skin or the hide, such pathogens find their way into meat or poultry during slaughtering and may cross-contaminate other foods that come in contact with the raw contaminated meat or poultry [7]. Meat and poultry can be contaminated during evisceration (the removal of the internal organs), where the stomach or intestines may burst and release bacteria that can contaminate the flesh (the raw meat or poultry prepared for human consumption) [25]. This evisceration of chickens or turkeys by the same equipment or knife can lead to the transfer of pathogenic *Campylobacter* and *Salmonella* from one infected bird to several others.

3.4 Post-harvest/Slaughter Contamination Factors

3.4.1 Food Processing/Preparation and Serving

Food processing is the transformation of agricultural products into foods or food ingredients. Food processing involves applying scientific and technological principles to preserve foods [26, 27]. Food preparation or processing can introduce pathogens into a product if not done properly [7]. One important factor of microbial contamination during food processing and preparation is the use of shared equipment, which may introduce pathogens from one food to another. Studies showed that *Listeria monocytogenes* has been found on food processing equipment and process surfaces, which are difficult to clean [25].

3.4.2 Unhygienic Practices of Food Handlers

Between production and consumption, foods can be in contact with different people handling the foods. Humans (their skin, mucous membranes, and cuts, open sores, or a skin infection) can serve as potential sources of pathogens from where foods can be contaminated if handled under unhygienic conditions, especially through unwashed hands [5]. Improperly cleaned hands, lack of aesthetic sense and personal hygiene, dirty clothes, and hair can be major sources of microbial contamination in foods [2, 8]. The presence of blemishes, pimples, boils, open wounds and soiled tissues, minor cuts and infection in hands, and mild generalized diseases such as flu, strep throat, or hepatitis A in an early stage can amplify the situation [2, 7]. Pathogens such as *Staphylococcus aureus, Salmonella serovars*, *Shigella spp*., pathogenic *E. coli*, and hepatitis A can be introduced into foods from human sources [2]. Handlers who do not wear gloves commonly spread Staphylococcus bacteria to meat, cream-filled desserts, potato salads, and egg products [7].

3.4.3 Biofilm Formation in Food Processes

During food processing, microbial colonies can inhabit or accumulate on critical places such as food contact and environmental sites on equipment to form biofilms. Biofilms are microbial cell clusters with a network of internal channels in the extracellular polysaccharide and glycoprotein matrix, which allows nutrients and oxygen to be transported from the bulk liquid to the cells [7]. Microbial colonies that form in critical places contaminate the surfaces and consequently the products made in that particular process [8]. Once a biofilm has been formed, it can be a source of contamination for foods passing through the same processing line [28]. Harmful microbes may enter the manufacturing process and reach the end product in several ways, such as through raw materials, air in the manufacturing area, chemicals employed, process surfaces, or factory personnel. Any microbe can form biofilm under suitable conditions. However, some microbes naturally have a higher tendency to produce biofilm than others. Foodborne pathogens that readily form biofilms include *Bacillus cereus, S. aureus, M. paratuberculosis, C. perfringens, E. coli 0157:H7, S. typhimurium, C.jejunii, Yersinia enterocolitica, and L. monocytogenes* [29]. *L. monocytogenes* has been found to form biofilms on common equipment and food contact surfaces, for example, plastic, polypropylene, rubber, stainless steel, and glass, which are sometimes difficult to clean [8]. Therefore, the design of the equipment and process line in the food processing and packaging industry is important for preventing the formation of biofilms and so improving process and production hygiene.

3.4.4 Packaging, Distribution, Marketing, and Storage

Packaging is an important stage in providing quality foods to consumers, as it protects foods from microorganisms, prevents loss of moisture, protects from temperatures that cause deterioration during handling, storage, and transportation. However, the packaging material may transfer food spoilage or pathogenic organisms to the packed food [7]. The routes of contamination from the packaging material to food include the surface, cutting dust, or direct contact with the raw edge of the paperboard [8]. Microbial contaminations can be also spread through contaminated containers and possible contact with decaying products during storage and distribution. Even in the refrigerator, cross-contamination takes place from raw meat, poultry, or fish drips onto vegetables or other ready-to-eat foods on the shelf below. Contamination also occurs when foods are not kept at the right temperature, thus promoting the temperature danger zone (i.e., the temperature in which bacteria and such can be the most widely spread) [7]. In addition, the spraying of contaminated water to give a fresh appearance to the vegetables also adds microbial contamination.

4 Factors Influencing Microbial Growth in Foods

All microorganisms require a set of factors that allow them to grow/live in certain environments. The various factors that influence the growth of microorganisms in foods are generally designated as intrinsic and extrinsic factors [2, 4]. In addition, there are other factors related to the characteristics of microorganisms, which are designated as implicit factors [4]. The manipulation of these factors allows to obtain products with a longer shelf-life and superior microbiological quality.

4.1 Intrinsic Factors

Intrinsic factors are those that are related to the physical–chemical characteristics of foods [4]. These factors have a preponderant action over microbial growth because almost all foods constitute a more or less favorable environment to the growth of most microorganisms. Like so, the type of nutrient contents [16, 30], pH [16], water activity [32–34], and oxygen [31, 35] are intrinsic factors that generally have a greater influence on microbial growth in foods.

Nutrient Contents: These nutrients required for microbial growth include carbohydrates, proteins, lipids, and small amounts of other materials such as phosphates, chlorides, and calcium [2, 16]. The growth of microorganisms can be controlled by controlling access and availability of corresponding nutrients [4, 31].

pH: Based on pH, foods can be grouped as high-acid foods (pH below 4.6) and low-acid foods (pH4.6 and above). Table 2.2 presents pH of some food items. The pH of a food has a profound effect on the growth and viability of microbial cells. Each species has an optimum and a range of pH for growth. In general, molds and yeasts are able to grow at lower pH than do bacteria: bacteria grow fastest in the pH range 6.0–8.0, yeasts 4.5–6.0, and filamentous fungi 3.5–4.0 [31]. The acidity of a product can have important implications for its microbial ecology and the rate and character of its spoilage.

Water Activity: For microbial growth, nutrients must enter the microbial cell through its cell wall. Therefore, nutrients must be soluble so that they can be carried into the cell by any free (or unbound) water that is available in the environment where the microbes are living (such as in food). The measure of this available free water is known as the water activity, or a_w, which ranges between 0 and 1. The a_w of food can be determined from its equilibrium relative humidity (ERH) by dividing

Table 2.2 pH of some common food commodities [40]

Item	Approx. pH
Apples	3.30–4.00
Bread, white	5.00–6.20
Cabbage	5.20–6.80
Egg white	7.96
Flour	6.00–6.30
Honey	3.70–4.20
Lime juice	2.00–2.35
Milk, cow	6.40–6.80
Oyster mushrooms	5.00–6.00
Sweet potatoes	5.30–5.60

Table 2.3 Minimum water activities at which active growth can occur [31–34]

Group of micro-organisms	Minimum a_w
Most gram-negative bacteria	0.97
Most gram-positive bacteria	0.90
Most yeasts	0.88
Most filamentous fungi	0.80
Halophilic bacteria	0.75
Xerophilic fungi	0.61

ERH by 100 (because ERH is expressed in percentage) [32–34]. Each microbial species (or group) has an optimum, maximum, and minimum a_w level for growth. Table 2.3 presents minimum water activities of different microorganisms at which active growth can occur. This information can be used to control spoilage and pathogenic microorganisms in food as well as enhance the growth of desirable types in food bioprocessing (such as adding salt in processing of cured ham) and in laboratory detection of microorganisms (adding salt to media to enumerate *Staphylococcus aureus*) [2].

Redox Potential: An oxidation–reduction (redox) reaction occurs as a result of the loss of electrons from a reduced substance (thus it is oxidized) and the gain of electrons by an oxidized substance (thus it is reduced). The tendency of a medium to accept or donate electrons, to oxidize or reduce, is termed as redox potential, E_h (measured in millivolts, mV) [31]. If free oxygen is present in a biological system, it can act as an electron acceptor [35]. Oxygen has a high redox potential and is a powerful oxidizing agent; thus, if sufficient air is present in a food, a high positive potential can result [31]. Increasing the access of air to a food material by chopping, grinding, or mincing can increase its redox potential. Similarly, exclusion of air as in vacuum packing or canning can reduce the redox potential [31]. The presence or absence of oxygen and the redox potential of food determine the growth capability of a particular microbial group in foods and the specific metabolic pathways used during growth to generate energy and metabolic by-products. This is important to understand and control microbial spoilage of foods (such as putrification of meat by *Clostridium* spp. under anaerobic conditions) and to produce desirable characteristics of fermented foods (such as growth of *Penicillium* species in blue cheese under aerobic conditions). Table 2.4 presents the redox potential of selected food materials [31].

4.2 Extrinsic Factors

Extrinsic factors are those related to food storage and environmental conditions [4], which include temperature, humidity, and gaseous environment. The relative humidity and gaseous condition of storage, respectively, influence the water activity and

Table 2.4 Redox potential of selected food materials [31]

	E (mV)	pH
Raw meat (post-rigor)	−200	5.7
Raw minced meat	+225	5.9
Cooked sausages and canned meats	−20 to −150	Ca. 6.5
Wheat (whole grain)	−320 to −360	6.0
Barley (ground grain)	+225	7.0
Potato tuber	Ca. −150	Ca. 6.0
Spinach	+74	6.2
Pear	+436	4.2
Grape	+409	3.9
Lemon	+383	2.2

redox potential of the food [2]. The influence of the storage temperature of food and the gaseous atmosphere on microbial growth is briefly discussed subsequently.

Temperature: Temperature is one of the most relevant factors in microbial growth. Microbial growth can occur over a temperature range from about −8 °C up to 61 °C at atmospheric pressure. The most important requirement is that water should be present in the liquid state and thus available to support growth [31]. Microorganisms in foods are mainly divided into three groups based on their temperature of growth, each group having an optimum temperature and a temperature range of growth [2]: (a) thermophiles (grow at relatively high temperature), with optimum at 55 °C and range 45–70 °C; (b) mesophiles (grow at ambient temperature), with optimum at 35 °C and range 10–45 °C; and (c) psychrophiles (grow at cold temperature), with optimum at 15 °C and range −5 to 20 °C. The correct use of temperatures during the maintenance of food and food products is fundamental for its preservation and longer shelf-life.

Gaseous Atmosphere: The presence and influence of oxygen on redox potential are important determinants of the microbial associations that develop and their rate of growth. Other than oxygen, there are other gases commonly encountered in food processing that also have microbiological effects. The inhibitory effect of carbon dioxide (CO_2) on microbial growth is applied in modified atmosphere packing of food and is an advantageous consequence of its use at elevated pressures (hyperbaric) in carbonated mineral waters and soft drinks [31]. Growth inhibition is usually greater under aerobic conditions than anaerobic and the inhibitory effect increases with decrease temperature, presumably due to the increased solubility of CO_2 at lower temperatures [31].

5 Health Impacts of Microbial Contamination of Food

The modality of foodborne microbial infection and toxication can be broadly classified into intoxication or poisoning, infection, and toxicoinfection.

Intoxication: Foodborne intoxication is caused by ingesting food containing bacterial toxins resulting from the bacterial growth in the food item [36]. For intoxication, a toxin has to be present in the contaminated food. Once the microorganisms have grown and produced toxin in food, consumption of viable cells cannot be required for illness to occur [2]. The foodborne bacteria that cause intoxication are *Clostridium botulinum, Staphylococcus aureus, Clostridium perfringens*, and *Bacillus cereus* [37].

Infection: Foodborne infection is caused by the ingestion of food and water contaminated with live enteropathogenic bacteria or viruses, which grow and establish themselves in the human intestinal tract [2, 36]. Viable cells, even if present in small numbers, have the potential to establish and multiply in the digestive tract to cause the illness. The foodborne bacteria that cause infection are *Salmonella* spp., *Listeria monocytogenes, Campylobacter jejuni, Vibrio parahaemolyticus, Vibrio vulnificus*, and *Yersinia enterocolitica*. The most common viral agents that cause foodborne disease are Hepatitis A, norovirus, and rotavirus [37].

Toxicoinfection: Illness occurs from ingesting a large number of viable cells of some pathogenic bacteria through contaminated food and water. Generally, the bacterial cells either sporulate or die and release toxins to produce the symptoms [2]. Some bacteria cause toxin-mediated infections while viruses and parasites do not. The foodborne bacteria that cause toxin-mediated infection are *Shigella* spp. and Shiga toxin-producing *Escherichia coli* [37].

The severity of the foodborne illness depends on the pathogenic microorganism or toxin ingested, the amount of food consumed (dose), and the health status of the individual. For individuals who have immunocompromised health conditions, or for the elderly population, children, or pregnant women, any foodborne illness may be life threatening [36]. The most common symptom associated with foodborne illnesses is diarrhea. Some other diseases caused by microbial contaminants are cholera, campylobacteriosis, *E. coli* gastroenteritis, salmonellosis, shigellosis, typhoid and paratyphoid fever, amoebiasis, and poliomyelitis [7]. Most foodborne illnesses are limited to brief episodes of diarrhea, nausea, or other acute gastrointestinal systems. Several other illnesses can result from the consumption of foods contaminated by microbial pathogens, which include fever, vomiting, weakness, chills and aches, headaches, abdominal pain, constipation, sore mouth, blurred vision, and muscle paralysis. In addition, septicemia, localized infection of other organs, and spontaneous abortion in pregnant women are the most severe acute illnesses associated with foodborne pathogen-contaminated food. Other complications associated with foodborne pathogens include reactive arthritis, hemolytic uremic syndrome (characterized by kidney failure), and Guillain-barre syndrome (characterized by neuromuscular paralysis) [7]. Table 2.5 shows some selected microbial contaminants, their commonly associated foods, and symptoms of illness.

Research showed that contaminated foods are alarmingly responsible for many more accidental fatalities than some products commonly perceived dangerous, including firearms, industrial machinery, and explosives [38]. Unsafe food is linked to the death of an estimated 2 million people annually including children [6]. Bacteria, parasites, and viruses, respectively, account for 72%, 21%, and 7% of

Table 2.5 Selected microbial contaminants, their commonly associated foods, and health impacts (symptoms) [7]

Microbial contaminant	Commonly associated foods	Health impacts (symptoms)
Bacillus cereus	Meat and vegetables dishes, cereals, spices, custards, puddings, and heat-treated desserts	Diarrhea and abdominal cramps; nausea and vomiting
Campylobacter species	Raw meats (beef and pork), water, unpasteurized milk, eggs, chicken, shellfish, and mushroom	Diarrhea (can be bloody), cramps, fever, and vomiting
Clostridium botulinum	Vegetables; improperly or home-canned or bottled foods, including canned meats, corn beef, canned fish, smoked fish and vegetables, honey, mushroom; improperly processed peppers, asparagus, soup, spinach	Vomiting, diarrhea, blurred vision, double vision, difficulty in swallowing, muscle weakness. Can result in respiratory failure and death
Clostridium perfringens	Raw meats, poultry, fish, stews, cooked turkey and beef, casseroles, gravy dressings, food that sits for extended periods, and dried foods such as spices and vegetables	Intense abdominal cramps and watery diarrhea
Cryptosporidium	Uncooked food or food contaminated by an ill food handler after cooking, contaminated drinking water	Diarrhea, stomach cramps, upset stomach, and slight fever
Escherichia coli OI57:H7	Ground beef, raw milk, chicken, vegetables and fruits, and any food exposed to raw fecal matter are at risk of being contaminated	Hemorrhagic colitis, severe (often bloody) diarrhea, abdominal pain and vomiting, little or no fever. Can lead to kidney failure.
Entamoeba hystolitica	Tap water, ice cream, ice cubes, shellfish, eggs, salads, raw or undercooked meat, peeled fruits, sauces	Amoebiasis; loose stool that may be bloody sometimes, stomach pain, fatigue, excessive gas, rectal pain, amoebic dysentery including high fever, severe abdominal pain
Hepatitis A	Raw produce, contaminated drinking water, uncooked foods, and cooked foods that are not reheated after contact with an infected food handler; shellfish from contaminated waters	Hepatitis (diarrhea, dark urine, jaundice, and flu-like symptoms, i.e., fever, headache, nausea, and abdominal pain)
Listeria monocytogenes	Dairy (soft cheeses and coleslaw), meat products(pate, sausages, and gas-packed delicatessen goods), cold-smoked and gravid rainbow trout products, sliced cold cuts, soft cheese, butter, ice-cream, coleslaw, raw vegetables, fermented raw-meat sausages, raw and cooked poultry, raw meats (all types), and raw and smoked fish	Fever, muscle aches, and nausea or diarrhea. Pregnant women may have mild flu-like illness, and infection can lead to premature delivery or stillbirth

(continued)

Table 2.5 (continued)

Microbial contaminant	Commonly associated foods	Health impacts (symptoms)
Noroviruses	Raw produce, contaminated drinking water, uncooked foods, and cooked foods that are not reheated after contact with an infected food handler; shellfish from contaminated waters	Viral gastroenteritis, acute nonbacterial gastroenteritis, food poisoning, or food infection (nausea, vomiting, abdominal cramping, diarrhea, fever, headache).
Salmonella	Raw meats, eggs, fish shellfish, poultry, milk and dairy products, fish, shrimp, frog legs, yeast, coconut, sauces, salad dressing, cake mixes, cream-filled desserts and toppings, dried gelatine, peanut butter, cocoa, chocolate, pork. In general, beef is less often contaminated with salmonella than poultry and pork	Acute gastroenteritis, painful abdominal cramps, diarrhea that may be sometimes bloody, fever (100 °F to 102 °F), vomiting, headache, and body aches
Shigella	Salads of potato, chicken, seafood and vegetables, milk and other dairy products, and meat products, especially poultry	Abdominal cramps, fever, and diarrhea. Stools may contain blood and mucus
Staphylococcus aureus	The red meats, especially ham, poultry, potato, macaroni and tuna salads, custard and cream-filled bakery product, the sandwich sauces	Sudden onset of severe nausea and vomiting. Abdominal cramps. Diarrhea and fever may be present
Toxoplasma gondii	Raw or undercooked meat, especially pork, or wild game and water	Fever, swollen lymph nodes, especially in the neck, headache, muscle aches and pains, sore throat: People in high group may develop brain inflammations, seizures, mental issues such as confusion and psychosis
Vibrio vulnificus	Undercooked or raw seafood, such as shellfish (especially oysters)	Acute gastroenteritis; vomiting, diarrhea, abdominal pain, blood-borne infection. Fever, bleeding within the skin, ulcers requiring surgical removal
Yersinia enterocolitis	Raw vegetables, milk produces, tofu, minced meat, raw pork from where other foods may be cross-contaminated	Lymph node inflammation, appendicitis-like symptom

deaths associated with foodborne transmission. Five pathogens account for over 90% of estimated food-related deaths are Salmonella (31%), Listeria (28%), Toxoplasma (21%), Norwalk-like viruses (7%), Campylobacter (5%), and *E. coli* O157:H7 (3%) [7]. Some food-related illnesses and deaths also result from unknown pathogens. Infants, young children, pregnant women, the elderly, and those with an underlying illness are particularly vulnerable. Worldwide, diarrheal diseases are second to respiratory diseases as a cause of adult death and are the leading cause of childhood death. In some parts of the world, they are responsible for more years of potential life lost than all other causes combined [5]. Each year, around 5 million children (more than 13,600 a day) die from diarrheal diseases in Asia, Africa, and South America. In the United States, estimates exceed 10,000 deaths per year from diarrhea and an average of 500 childhood deaths are reported [7]. A particular study showed that, in Nigeria, more than 200,000 people die annually from food poisoning caused by contaminated foods through improper processing, preservation, and service [7, 39].

6 Conclusion

Microbial contamination of food is a serious public health concern worldwide. To ensure safe and reliable supply of food, mitigation of microbial contamination and the consequential impacts is of paramount importance. Control of food microbial contamination and the consequent impacts must take place from the primary production to the dining table. The best practice is to prevent microbial contamination through good agricultural practices. Different preventive measures such as good agricultural practices, good manufacturing practices, good hygienic practices, good transportation practices, and good storage practices can be implemented to minimize microbial food safety hazards [7]. The exclusion and control of the well-estimated risk factors through the above-mentioned practices can help to develop safe food all over the world and reduce the socioeconomic burden of foodborne diseases [41]. Most importantly, food safety education for consumers and staff in the food industry is integral for the prevention of food contamination and its consequences and should be promoted widely. Proper measurement methods to measure microbial and chemical contaminants are required to produce safe and healthy foods.

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