Food Spoilage and Food Contamination

Z. R. Azaz Ahmad Azad, Mohd. Fahim Ahmad, and Waseem Ahmad Siddiqui

Abstract The interaction of versatile nutrients and enzymes present in food leads to several degradative chemical changes that deteriorate the quality and shelf life of food. The deteriorative changes are enhanced by contamination that occurs at various stages of processing, handling and storage. The undesirable changes include lipid oxidation, enzymatic or non-enzymatic browning, putrefaction and toxicity due to hazardous substances. Contamination occurs from various physical, chemical and biological sources and is affected by external factors such as temperature, poor hygiene and sanitation. The intrinsic factors such as pH, redox potential, water content and the presence of antimicrobial substances in food also affect the degree of contamination and thereby the spoilage. Most of the contaminants occur from natural sources but some are added as a result of human activities. Contamination leads to spoilage of food due to the microorganisms, enzymes, chemical reactions (harmful additives, mycotoxins, bacterial toxins and radiations) and physical changes (caused by freezing, burning, drying, pressure). Spoilage changes the nitrogenous organic compounds in food into alpha-keto acids, ammonia, propionic acid, amides, imides, and urea. The organic acids are oxidized to carbonates causing the medium to become more alkaline and the consumption of contaminated and spoiled food can lead to various food borne illnesses and intoxication. Therefore, it is necessary to implement and maintain proper food hygiene during processing and storage. The various techniques such as biosensors, apt sensors and spectroscopy with chemometrics analysis for the quantitative assessment of food spoilage may be incorporated. The chapter focused on different aspects of food sanitation, microbiology, contamination, personal hygiene, spoilage and the effective measures to increase the shelf-life of the food and food products.

Keywords Contamination · Spoilage · Sanitation · Food safety · Adulteration

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Introduction

Foods are essential and highly complex materials. The properties of constituents and their handling during processing determine the quality and shelf-life of foods. Over the last few decades, the food industry has grown tremendously. The sanitary and hygienic practices have also changed and now become more complex (Banwart 1979). The processing, preparation and preservation of food depends on a more mechanized and large-scale process.

The issue of food scarcity is of higher importance to combat the hunger, improve food security and income of the world's poorest as well as underdeveloped countries. Food losses or wastage have a negative impact on food security, food quality and safety, economic development and on the environment (Bryan 1979). Food losses may be affected by crop production choices and pattern, internal infrastructure and capacity, marketing chains and channels for distribution, and consumer purchasing and food use practices. To ensure the availability of good quality and appropriate quantity of food to every inhabitant of this planet, it is necessary to reduce the postharvest losses. Recently worldwide postharvest vegetables and fruit losses are higher than 30–40% and even much higher in developing countries. The prospects are also that the world population will grow from 5.7 billion inhabitants in 1995 to 8.3 billion in 2025. World production of vegetables amounted to 486 million ton, while that of fruits reached 392 million ton. Reduction of post-harvest losses reduces cost of production, trade and distribution, lowers the price for the consumer and increases the farmer's income. India is the major producer of fruits and vegetables and stands next to Brazil and China in the world. That means it contributes 10% of world fruit production and 14% of total world vegetable production. According to the India Agricultural Research Data Book 2004, the losses in fruits and vegetables are to the tune of 30%.

Foods may be contaminated due to biological contaminations, physical contamination, chemical contamination and cross-contamination. Food deterioration is caused by the growth of microorganisms, the chemical reaction with their environment, or the presence of foreign bodies in foods. Food spoilage is a complex process and even with modern conservation and preservation techniques, large amount of food is spoiled due to microbes. Despite the heterogeneity of raw materials and processing conditions, the microbial flora produced during food storage and deterioration may be based on source, matrices and conservation parameters. Often foods contain a variety of organisms, most of them being saprophytes. Their existence is inevitable because they mainly come from the environment in which food is prepared or processed and it is difficult to eliminate them completely (Fields 1979; Marriott 1994; Frazier and Westoff 1996; Berthiller et al. 2013). However, by changing the environmental conditions, their numbers or activity can be reduced. Therefore, understanding the factors that promote or inhibit their growth is essential to understand the principles of food preservation. Most foods are an excellent medium for the rapid growth of microorganisms for being rich in organic matter, sufficient water content with a neutral or slightly acidic pH (Felix 1992) (Fig. 1).

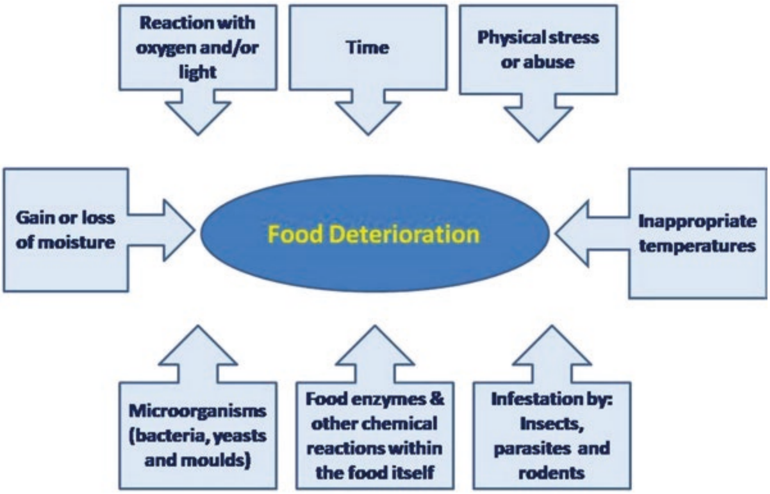

Fig. 1 Factors causing food deterioration

Foods consumed by humans and animals are ideal ecosystems where bacteria and fungi can multiply. The presence of micro-organisms in foods in small numbers may not be harmful, but their unrestricted growth makes food unfit for consumption due to damage or degradation. Many foodborne microbes are found in healthy animals (in the intestine) that are consumed as food. Meat and poultry carcasses can be contaminated during slaughter by human touch or unsanitary conditions (Niven Jr 1987). Salmonella species can infect chicken ovary so that the internal contents of normal eggs can be contaminated with the bacterium (Lechowich 1980). The shellfish and oysters can concentrate Vibrio bacteria that are found naturally in seawater. Similarly, fresh fruits and vegetables may be contaminated if they are washed or irrigated with water contaminated with animal manure or human sewage (Fig. 2).

At a later stage in food processing, food-laden microbes can be introduced from an infected person or by mutual contamination from other raw agricultural products. For example, *Shigella*, Hepatitis A virus (HAV), and Norwalk virus can be introduced from unwashed hands of infected food connoisseur themselves. In the kitchen, microbes can move from one food to another using the same knife, kitchen/cutting board or other tools to prepare food without washing the cutting surface or cooking pots. Even fully cooked food can be infected if raw or cold food is touched or mixed that contain microbial pathogens. Bacteria need to multiply in large numbers in food to cause disease. Due to the warm and wet conditions and adequate supply of nutrients, the bacteria multiply every half an hour and produce millions of strains within 12 h. As a result, the food can be contaminated overnight and become highly contagious the next day. If food is cooled, the bacteria multiply at a slower rate. In general, freezing prevents bacteria from growing and multiplying and generally maintains them in the state of suspended animation. However, *Listeria monocytogenes* and *Yersinia enterocolitica* can actually grow at refrigeration temperatures.

Fig. 2 Spoiled food and food products

Classification on the Basis of Stability of Foods

Foods are often classified based on being non-perishable, semi-perishable or perishable. The heat-treated and canned foods are often listed as non-perishable. However, canned food may become susceptible to damage under certain circumstances, when chance exists to re-pollinate due to damaged cans, rust or others so that it is not tightly closed. The semi-perishable foods are usually dry goods, such as flour, legumes, hard cheese, dried fruits, vegetables, and even tarpaulins. Most of the food items fall in the category of perishable. The perishable foods include fruits and vegetables, eggs and poultry, meat and fish, in addition to all cooked food. Frozen foods, although primarily perishable, can be classified as semi-perishable provided they are stored properly. However, it is important to note that almost any type of food will spoil if it is wet and unfrozen and the damage would occur faster at warmer temperature (Table 1).

Table 1 Spoiled food and food products

Non-perishable	Semi-perishable	Perishable
• Stay good for a year or more without freezing or refrigeration. • Examples: Sugar, legumes, cereals, oils, pickles, etc. • Storage in a cool and dry place is however, necessary	• Stay good for weeks to months, if stored properly. • Examples: Flours, fruits such as apples, vegetables such as potatoes and onions, frozen foods, etc.	• Spoil within a few days. • Examples: Milk, eggs, meat, fish, poultry, and most fruits and vegetables, especially green leafy vegetables.

Food Spoilage

Food spoilage may be defined as deterioration of food to the point in which it is not edible to human or its quality of edibility reduces. Such changes can be detected by smell, taste, touch or sight. These changes can be caused due to air and oxygen, moisture, light, temperature, chemical and biological means. The latter includes the action of enzymes, microorganisms, insects and contamination by Trichinella (Moral et al. 2017; Manisha 2018). It is estimated that spoilage due to microorganisms alone causes the loss of almost one quarter of the world's food supply. Many foods may not be degraded but contain certain types of bacteria or toxins that make it unfit for human consumption.

The criteria of a particular food suitable for human consumption are:

(a) It should be in the desired condition and maturity.
(b) It should be free from contamination throughout production and handling procedures.
(c) It should be free from chemical and physical changes caused due to pressure, freezing, heating, drying, etc. during processing, handling and storage, and because of the action of enzymes, microorganisms, parasites, insects and rodents.

Types of Spoilage

The food may become unsuitable or unacceptable for human consumption due to the following reasons:

(a) Growth of micro-organisms such as bacteria, yeasts and molds; the most common and most important cause of food spoilage.
(b) Activity of enzymes within the food (e.g., enzymatic browning).
(c) Infestation of pests such as insects and rodents.
(d) Non-enzymatic chemical changes in the food e.g., chemical oxidation of fats producing rancidity and browning due to Maillard reaction.
(e) Physical damage caused by drying (caking), freezing (freezer burn), etc.

Microorganisms and Food

The microbial damage to food is the beginning of a complex natural process of degradation that recycles the elements in animal or plant tissues into the environment. Microorganisms that may cause food damage include molds, yeast and bacteria. The general sources of food spoilage microorganisms are the air, soil, sewage, and animal wastes. Pollution with molds is, as a general rule, easily detected by the presence of fictitious strands or string-like structures which, in many cases, are colored. They often contribute a musty smell and flavor to the food in which they are found. However, some molds, are not completely harmful. Semi-humid or low-water foods are partially dry and the water is sufficient to maintain bacterial growth which is ideal for pollination with mold and yeast. Yeasts are small single-celled organisms which multiply by budding. In general, sugars are the best source of energy for yeast and carbon dioxide and alcohol are the end products of fermentation. Yeast damage is usually identified by bubbles, aroma and alcoholic taste (Pretorius 2000). Bacteria destroy food in many ways and it is not always possible to identify damage through sight, smell or taste. Unfortunately, some bacteria that cause suffering from a health point of view may multiply without altering the appearance, smell or taste of food (Nesse and Williams 2012). Microorganisms may include the original flora of food, as well as the added contaminants during handling, processing, transport, storage, preparation and presentation.

Microorganisms Present in Food

(a) **Bacteria**: Being prokaryotes, bacteria are much smaller than the eukaryotic microbes like yeasts. They come in different sizes and shapes and usually possess a cell wall. Bacteria can bring about a variety of changes in the food, most of which may be undesirable. The changes include pigment production, lysis of complex nutrients, production of foul smelling volatile substances and production of toxins. Many bacteria can form endospores which may survive harsh treatments like chemicals, radiation and heat.

(b) **Yeasts**: Yeast cells are larger in size and grow at a slower rate than bacteria. Most of the yeasts prefer high water activity (a_w) and mild acidic conditions. Yeasts are more likely to grow in packaged, low-pH foods such as fruit juices. Growth of yeast may make the foods smelly, feel slippery, and turbid (in case of clear juices).

(c) **Molds**: molds may have different colors but usually have cotton-like texture and appearance. They are spread as tiny spores that germinate wherever nutrient source is available. Due to the formation of spores, molds can survive wide ranges of temperature and pH. Molds prefer near neutral pH, room temperature and high a_w, but can grow in low or high pH as well as very low a_w conditions. In fact, under low a_w conditions, they can outgrow bacteria and yeasts.

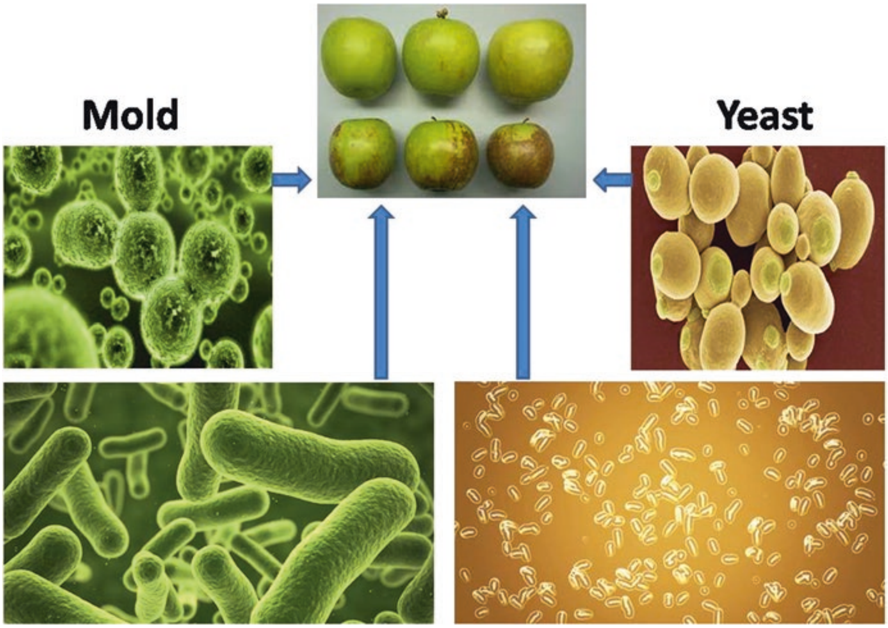

Fig. 3 Microbes causing deterioration in foods

(d) **Viruses**: Although not considered as true living organisms, viruses are important to discuss as they also affect the quality of food. Viruses do not consume or degrade the food nutrients but may be carried by contaminated food to cause various food-borne viral infections (Fig. 3).

Microbial Growth

The mode of reproduction in bacteria is asexual, in which a bacterium divided into two daughter cells, by the process called binary fission. If the number of dividing cells exceeds unity on average, the bacterial population undergoes exponential growth. The measurement of bacterial exponential growth curve in batch culture requires bacterial enumeration (cell counting) by direct and individual (microscopic, flow cytometry), direct and bulk (biomass), indirect and individual (colony counting), or indirect and bulk (most probable number, turbidity, nutrient uptake) methods (Skarstad et al. 1983). The growth of spoilage microorganisms in food depends on many factors e.g., type of organism, ability to extract nutrients from food, competition with other microorganisms, microbial load and environmental conditions. There are four distinct phases of the growth curve of bacteria and other microorganisms:

(a) **Lag phase**: This is the phase during which the bacteria adapt themselves to the new environment. During this phase, there is no or little increase in the number of bacteria. During this phase, the bacterial growth cycle, synthesis of RNA, enzymes and other molecules occurs. The duration of lag phase depends on several factors including the type of bacteria, the initial number and condition of cells, the type and concentration of nutrients in the new environment, temperature, etc. (Robinson et al. 1998). This period of little to no cell division and can last for 1 to several hours. Good hygiene would lower the initial number of bacteria and hence, would increase the lag phase.

(b) **Logarithmic or exponential phase (Log phase)**: During this phase, the bacterial population grows exponentially and doubles at an interval equal to their generation time (or doubling time, the time of bacterial reproduction). If growth is not limited, doubling will continue at a constant rate so both the number of cells and the rate of population increase doubles with each consecutive time period. For such type of exponential growth, plotting the natural logarithm of cells against time gives a straight line. The slope of this line is the specific growth rate of the organism, which is a measure of a number of divisions per cell per unit time. This phase may last up to several hours under optimal nutrient conditions. The duration of this phase is also dependent on several factors including availability of nutrients (Rauprich et al. 1996).

(c) **Stationary phase**: This phase is the result of depletion of growth limiting factors such as the essential nutrients, and/or formation of inhibitory products such as organic acid. As the nutrient concentration depletes the bacteria enter the stationary phase. During this phase, the net growth is zero, i.e., growth rate is equal to death rate. As a result, a smooth horizontal linear part of the curve during the stationary phase. However, bacteria still remain metabolically active. Many microorganisms produce secondary metabolites during this stage which affect the chemical composition of the medium in which they are growing. Many of these secondary metabolites are moderately to highly toxic (Ayoola 2007). The duration of this phase may vary from several hours to several days depending on the type of microorganism and the availability of nutrients.

(d) **Death or decline phase**: Once the nutrients further deplete and toxic waste further accumulate, the death phase commences. This phase, at least, in early stage, is also logarithmic. Several factors determine the time of commencement and duration of this phase. Once the population is drastically reduced by the early death phase, a slowdown in the death rate is observed (Fig. 4).

Bacteria need about four hours to adapt to the new environmental conditions before they begin to grow rapidly which means that there are less than four hours to decide whether one has to cool, heat or eat the food. With the growth of microorganisms, they tend to form colonies and the secretions from this large population of cells become toxic. This is the fixed stage in which some cells begin to die. If the growth of bacteria is controlled, then the main cause of food damage is limited (Sallam 2007). The proliferation of perishable organisms depends on the nutrients

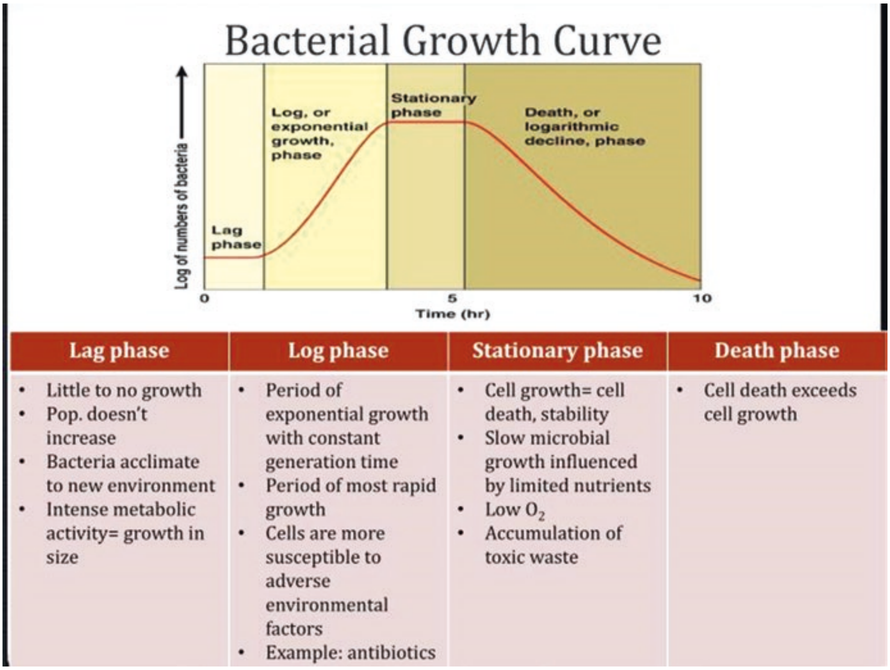

Fig. 4 Bacterial growth curve (Adapted from https://slideplayer.com/slide/6092622/)

and many other factors—the type of organisms involved, competition from other microorganisms, environmental conditions etc.

Factors Affecting Food Spoilage

Food spoilage and deterioration is a naturally occurring process. The microorganisms grow best at room temperatures (60–90 °F), but most do not grow well at refrigerator or freezer temperatures. The major reason for food spoilage is caused by the increase in the number of microorganisms, utilization of nutrients, causing enzymatic changes results in bad flavors due to breakdown of some food components or synthesis of new compounds. Because of these microbial activities food becomes unfit for human consumption. These microbes can oxidize reduced carbon; nitrogen and sulfur compounds present in dead plants and animals and can contribute the minerals to the biogeochemical cycle. Most foods contain enough nutrients to support microbial growth, promote serial factors, inhibit or limit the growth of microorganisms in food (Zottola 1972). Factors influencing microbial growth are divided into two types—intrinsic and external parameters. Microflora components compete with one another over the available nutrients and fastest growth under a given set of conditions becomes dominant causing septic symptoms. The component of microorganisms that become dominant is determined by the complex interaction between contaminated microflora components (implicit factors), the storage environment (external factors) and the physico-chemical properties of food (internal factors) (Lemus-Mondaca et al. 2012; Perhar and Arhonditsis 2014). The knowledge of the intrinsic and extrinsic parameters should be able to determine the broad range of organisms which may be present in a particular type of food, for example, whether the food may be destroyed by bacteria, yeast or mold. The foods with high water content and a pH above 5.0 are likely to be destroyed by bacteria because they grow fastest under these conditions (Pelczar et al. 1993). Even if the water activity is high, foods with a pH lower than 4.2 may be destroyed by yeast and mold.

Extrinsic Factors

These are the external environment factors that affect the growth of micro-organisms. Some important extrinsic factors are:

Temperature

Microorganisms can grow over a wide range of temperatures. The environmental temperature not only determines the propagation but also the species of microorganisms that will flourish and the extent their activity. For example, changing the temperature to just a few degrees may favor the growth of a new organism and a different type of food damage and poisoning. The lowest temperature at which microorganism has been reported to grow is −34 °C; the highest is somewhere in excess of 100 °C. But some spore producing bacteria such as *Bacillus stearothermophilus*, *Clostridium tetani* and *Clostridium perfringens* can grow above 100 °C. Based on temperature ranges upon which microbes grow, microorganisms are classified as three groups-

1. Psychrotrophs (cold temperature tolerant microorganisms) or Psychrophiles (cold temperature loving microorganisms) can tolerate temperatures as low as freezing temperatures. These microbes can grow between the temperature ranges of 2 °C to 20–30 °C. The most important psychrotrophs include *Alcaligenes, Shewanella, Brochothrix, Corynebacterium, Flavobacterium, Lactobacillus, Micrococcus, Pectobacterium, Pseudomonas, Psychrobacter, Enterococcus* and others. The psychrotrophs found most common on foods are those that belong to the genera *Pseudomonas* and *Enterococcus.* These organisms grow well at refrigerator temperature and cause spoilage at 5–7 °C of meats, fish, poultry, eggs and other foods normally held at this temperature.

2. Mesophiles (microorganisms that require close to room temperature condition), which grow best between 20 and 45 °C (e.g., *Bactobacilli, Staphylococci*). Mesophilic species and strains are known bacteria among all genera and may be found on food held at refrigerator temperatures.
3. Thermopiles (microorganisms that grow well at high temperatures), which have growth optima at temperatures ranges of 55 °C–65 °C (e.g., *Bacillus, Lactobacillus*). Most important thermophiles in food belong to the genera *Bacillus, Paenibacillus, Clostridium, Geobacillus, Alicyclobacillus,* and *Thermoanaerobacter.*

Like bacteria fungi are also able to grow over wide ranges of temperature. Many molds are able to grow at refrigerator temperatures, especially some strains of *Aspergillus, Cladosporium* and *Thamnidium*, which may be found growing on eggs, sides of beef and fruits (Jay et al. 2005). Yeasts prefer psychrotrophic and mesophilic temperature ranges but generally not within the thermophilic range.

Atmospheric Gases

Several studies showed that the antimicrobial activity of gases at ambient and subambient pressures on microorganisms important in foods (Loss and Hotchkiss 2002). Gases inhibit microorganisms by two ways. (1) They can have direct toxic effect that can inhibit the growth and proliferation. Carbon dioxide (CO_2), ozone (O_3) and oxygen (O_2) are gases that are toxic to certain microbes. It is dependent upon the physical and chemical properties of gases and its interaction with aqueous and lipid phases of foods. Oxidizing radicals generated by O_3 and O_2 are highly toxic to anaerobic bacteria and can having an inhibitory effect on aerobic depending on their concentration. CO_2 is effective against obligate aerobes and at high level can deter other microorganisms. (2) Second inhibitory mechanism is achieved by modifying the gas composition, which has indirect inhibitory effects by altering the ecology of the microbial environment. Atmospheres that have a negative effect on the growth of one particular microorganism may promote the growth of another. This effect may have positive or negative consequences depending upon the native pathogenic micro flora and their substrate. Nitrogen replacement of oxygen is an example of this indirect antimicrobial activity (Moral et al. 2017). As with temperature, the availability of oxygen determines which microorganisms will be active. Some microorganisms have an absolute demand for oxygen, while other organisms grow in the total absence of oxygen. However, other microorganisms can grow either with or without available oxygen. Microorganisms that require free oxygen are called aerobic microorganisms (e.g., *Pseudomonas* sp.). Organisms that grow in the absence of oxygen are called anaerobic microorganisms (e.g., *Clostridium* sp.). Microorganisms that can grow with or without free oxygen are called optional microorganisms (e.g., *Lactobacillus* sp.).

Relative Humidity

The relative humidity (RH) of the storage environment is important extrinsic parameter both from the standard point of a_w within foods and the growth of microorganisms at the surfaces. When food with low aw contents are placed in high RH environments, the foods takes up more moisture until equilibrium has been established. Similarly foods with a high a_w lose moisture when placed in an environment of low RH. There is a relationship between RH and temperature that should be borne in mind in selecting proper storage environment for foods. Generally, if the temperature is high then the RH low and vice versa. All microorganisms have high water requirements to support their growth and activity. High relative humidity can cause moisture condensation on food, equipment, walls and ceilings. Condensation causes wet surfaces, which lead to microbial growth and damage. Also, microbial growth is inhibited by low relative humidity (Wihan 2007). Microbial bacteria require higher relative humidity than different organisms. The optimal relative humidity of bacteria is 92% or higher, while yeast needs 90% or higher, and for molds, the relative humidity should be 85–90%.

Intrinsic Factors

These are the internal factors related to the properties of the substrates (food or debris) that affect the type and growth of microorganisms. The more important intrinsic factors are:

Water Activity (a_w)

Water is an excellent solvent for all life processes in every living organism for biocatalytic activity. The amount of water required varies for different organisms. Water is required by micro-organisms, and a reduction of water availability constitutes a method of food preservation through reduction of microbial proliferation. It is important to recognize that it is not the total amount of moisture present that determines the limit of microbial growth, but the mount of moisture which is readily available for metabolic activity. The unit of measurement for water requirement of microorganism is usually expressed as water activity (a_w). It is defined as the vapor pressure of the solution divided by the vapor pressure of the pure solvent: $a_w = p/p_o$, where p is the vapor pressure of the solution and p_o is the vapor pressure of pure water. The optimal a_w for the growth of micro-organisms is 0.99, and most microbes require an a_w higher than 0.91 for growth. The relationship between relative humidity (RH^W) and a_w is $RH = a_w \times 100$. Therefore an a_w of 0.95 is equivalent to an RH of 95% generally. Pure water has an a_w of 1.00, a 22% NaCl solution (w/v) has an a_w of 0.86, and a saturated solution of NaCl has an a_w of 0.75. The water activity (a_w) of most fresh foods is above 0.99. In general bacteria require more water activity

Table 2 Lowest tolerable a_w values for different types of microorganisms involved in food spoilage

S. No.	Group of microorganisms	Minimal (a_w) value
1.	Bacteria	0.91
2.	Yeasts	0.88
3.	Molds	0.80
4.	Halophilic bacteria	0.75
5.	Xerophilic fungi	0.65
6.	Osmophilic yeasts	0.60

than molds and yeasts. Gram negative bacteria have higher water requirement than gram positive bacteria (Grant 2004). Molds normally have the lowest a_w requirements, with yeasts being intermediate. Most spoilage bacteria do not grow at an a_w below 0.91, but molds and yeasts can grow at an a_w of 0.80 or lower. Molds and yeasts are more likely to grow in partially dehydrated surfaces (including food), whereas bacterial growth is retarded (Table 2).

The effect of lowering a_w below optimum is to increase the length of the lag phase of growth and to decrease the growth rate and size of final population of microorganisms. This is due to adverse influences of lowered water on all metabolic activities in microorganisms since all chemical reactions in cell require an aqueous environment.

pH

All the microorganisms have a minimal, maximal and optimal pH for their growth, survival and activity of their enzymes. Influence of pH of food not only has effect on growth of microorganisms but also on processing conditions. Food having acidic contents promotes growth of acid loving microorganisms such as yeasts, molds and some acidophilic bacteria. Molds can grow over a wider range of acidic pH than bacteria and yeast. Most of the fermentative yeasts can grow at pH of about 4.0–4.5, as in fruit juices and acid food such as sauerkraut and pickles (Seideman et al. 1976). A food with an acid pH would tend to be more microbiologically stable than neutral or alkaline food. Because of this restrictive pH the food such as fruits, soft drinks, fermented milks, sauerkraut and pickles and stable against bacterial spoilage. Most of the bacteria, except acid fermenters are favored alkaline or neutral pH. Most of the bacteria preferred a pH range between 7.0 and 7.5 but some proteolytic bacteria can grow on food substrate with high pH. The buffer content in the food is important to maintain the stability against microbial spoilage. Buffers permit an acid (or alkali) fermentation to go on longer with a great yield of products and organisms (Heller 2001). Vegetable juices have low buffering capacity permitting a decrease in pH with the production of only small amount of acid by the lactic acid bacteria during the early stage of sauerkraut and pickle fermentation. This helps to inhibit the growth of pectin hydrolyzing and proteolytic competing bacteria in food.

The pH for optimal growth of most micro-organisms is near neutrality (7.0). Yeasts can grow in an acid environment, but grow best in the intermediate acidic 4.0–4.5 range. Molds tolerate a wider range of pH (2.0–8.0), although their growth is generally greater in acid pH. Molds can thrive in a medium that is too acid for either bacteria or yeasts (Fleet 2011). The bacterial growth is usually favored at near-neutral pH values. However, acidophilic (acid-loving) bacteria will grow on food or debris down to a pH value of approximately 5.2. Below pH 5.2, microbial growth is dramatically reduced when compared to growth in the normal pH range.

Oxidation-Reduction Potential

The potential of reducing oxidation is an indicator of oxidizing strength and the ability to reduce the substrate. The reducing and oxidizing power of the food will influence the type of organism and chemical changes produced in the food. The concentration of oxygen in food, chemical composition and type of microorganisms associated contribute to the oxidation-reduction (O-R) potential of food and affect growth of microorganisms in them (Lobo et al. 2010). The redox potential of food is determined by characters such as- (a) Oxygen tension of atmosphere above the food, (b) access of atmosphere to the food, (c) resistance of food to the changes occurring and (d) O-R state of materials present in food. Aerobic microorganisms grow more easily with high potential to reduce oxidation (oxidizing reaction). Microorganisms can alter the redox potential of food to the extent that the growth of other microorganisms is restricted. For example, many organisms can reduce the availability of oxygen to a level so that the growth of other aerobes is discouraged.

The O-R potential is written as Eh and measured and expressed as millivolts (mV). If the substrate is highly oxidized would have a positive Eh and substrate is reduced is a negative Eh. Aerobic microorganisms such as bacilli, cocci, micrococci, pseudomonas, acinetobacters require and grow at positive O-R potential and anaerobic such as clostridia and bacteroides require negative O-R potential for their growth.

Most of the fresh plant and animal food have low redox potential because of reducing substances present in them. Fresh vegetables and fruits contain reducing substances such as ascorbic acid, reducing sugars and animal tissues have sulfhydral (-SH) and other reducing group compounds considered as antioxidants.

Fresh vegetables, fruits and meat promote growth of aerobic microorganisms in the surface region because of positive redox potential (Petersen et al. 1999). However the anaerobic microorganisms grow in inner parts of vegetables, fruits and meat because of negative redox potential. Most of processed plant and animal food gain positive redox potential therefore promote growth of aerobic microbes.

Types of Nutrients

Nutrients are one of the most important compounds for the growth and functioning of all living beings. Nutritional quality of food depends on the chemical composition, nutritive value or nutrients, their proportion and growth promoting ability to the microorganisms.

The most important factors which have to be considered are the energy substances in food, nitrogen substances, growth promoting substances, accessory food substances or vitamins, minerals and water content which all are essential for growth or energy production of organisms. The common energy sources of organisms are carbohydrates. Complex carbohydrates such as cellulose, hemicelluloses, starch, pectin etc. can be utilized by various types of microorganisms. At the same time other carbon compounds such as esters, alcohols, peptides, amino acids, organic acids and their salt also serve as energy sources for many organisms (Longree and Armbuster 1996). Bacteria are identified and classified based on their ability to utilize various sugars and alcohols. Most organisms can hydrolyses complex carbohydrates and can use glucose as energy source. Some microorganisms can hydrolyze triglycerides and other types of fats by microbial lipases and produce glycerol and smaller fatty acids. Hydrolytic products of proteins and peptides serve as sources of nitrogen for many proteolytic bacteria such as *Pseudomonas* spp. The primary nitrogen source utilized by heterotrophic microorganisms is amino acids. Some microbes are able to utilize nucleotides and free amino acids, whereas others are able to utilize peptides and proteins (Thomas and Surdin-Kerjan 1997). Molds are most effective in using proteins, complex carbohydrates and fats because they contain enzymes capable of decomposing these molecules into less complex components. Many bacteria have similar capacity, but yeast requires simple compounds. Some microorganisms require vitamins and other growth factors for their growth and development such microbes are called fastidious organisms. Some microbes produce vitamins and other growth factors which support growth of other organisms present in food. Each kind of microorganisms has a range of food requirement.

Inhibitory Substances

Inhibitory substances are present in the food as its own origin, or added purpose fully for preventing and inhibiting the growth of microbes. The stability of certain foods against attack by microbes is due to the presence of certain naturally occurring substances that possess and express antimicrobial activity. Some plant species are known to contain essential oils that possess antimicrobial activity. Eugenol in cloves, allicin in garlic, cinnamic aldehyde and eugenol in cinnamon, allylisothiocyanate in mustard, eugenol and thymol in sage and carvacrol (isothymol) and thymol in oregano are some of the best studied examples. Milk contains several antimicrobial substances, including lactoferrin, conglutinin and the lactoperoxidase system. Lactoferrin is an iron-binding glycoprotein that is inhibitory to a number of foodborne bacteria and its use as a microbial blocking agent on beef carcasses (Gillespie 1981; Gravani 1987). Eggs contain lysozyme; ovotransferrin and conalbumin having antimicrobial properties.

Deteriorative Changes Brought About by Microorganisms

Growth of microorganisms brings about rot and decay in the food. Food that has undergone microbial decay is considered unfit for human consumption. Some of the most common physical and chemical changes caused by microorganisms have been discussed below:

Physical Changes in Foods

Physical damage brought about by microorganisms is usually more pronounced than chemical changes. The microbial damage usually results in a considerable change in the physical properties of food such as flavor, odor, and color. Food damage can either be categorized as aerobic or anaerobic depending upon the type of process, or on the basis of the causative agent such as bacteria, mold or yeast. Aerobic damage is usually caused by bacteria and yeast in the formation of mud such as odors and unwanted taint, color change and flavor of fat breakdown (Garbutt 1998). The formation of mud by certain types of bacteria or yeast depends on environmental conditions, especially temperature change and the oxidation dye—lead, grey, brown or green color. The physical deterioration by molds leads to a viscous surface of foods, the appearance often referred as “whiskers”. Mold deterioration can affect the appearance of fat in food similar to those found in bacteria and yeast, and produce unpleasant odor and alcohol flavor.

Aerobic damage to food from molds is usually restricted to the surface of the food which can be trimmed in foods such as meat and cheese, and the rest is generally acceptable for consumption (Marsh and Bugusu 2007). The surface beneath the molded growth is usually limited in microbial activity. However, if the growth on the surface is followed by penetration within the surface of the food it may contain toxins. Anaerobic damage occurs within the food products or in a closed container where oxygen is either absent or limited. Therefore, the damage caused by bacteria is through disintegration, decay or contamination. Further degradation occurs due to the accumulation of organic acids after the enzymatic degradation of complex molecules (carbohydrates). Also, proteins without rot can contribute to stress accompanied by the production of different gases.

Chemical Changes in Foods

Chemical changes occur due to the activity of enzymes present in the food, and enzymes produced by microorganisms. Due to different intrinsic and microbial enzymes, proteins, fats, carbohydrates and other complex molecules decompose into smaller and simpler compounds. With increased load and microbial activity, the rate of the process of degradation is enhanced. The availability of oxygen determines the end products of the bacterial action such as the normal hydrolysis of proteins and carbohydrates into final products amino acids and glucose. Under anaerobic conditions, proteins decompose into a variety of sulfur-containing compounds, which generally have offensive odor and taste (Thomas and Surdin-Kerjan 1997). Other chemical changes include the action of lipases, produced by microorganisms that hydrolyze the triglycerides and phospholipids into glycerol and fatty acids. Most microorganisms use carbohydrates as preferential energy source leading to the formation of a variety of end products such as alcohol and organic acids. However, in sausage and cultured dairy products, a controlled microbial fermentation of organic acid (lactic acid) contributes to its distinctive and unique flavor.

Food Contamination

Food contamination is the introduction or occurrence of contaminants in food. Contaminant refers to any biological or chemical agent, foreign body or other substance that is unintentionally added to food which may endanger food safety. Chemically contaminated food is a global health issue and a major cause of international trade concern. Contamination can occur through environmental pollutants such as toxic heavy metals, polychlorinated biphenyls (PCBs) and dioxins or through deliberate use of chemicals such as pesticides, animal drugs and agrochemicals. Food additives and contaminants from food production and processing can also adversely affect health. When food is contaminated with pathogens, chemical contaminants or heavy metals, they can pose serious health risk to consumers and impose a severe financial burden on individual or communities. Cross-contamination of food is a common cause of foodborne illness (Guthrie 1988). During food preparation and storage, food may be contaminated by microorganisms (bacteria and viruses) from different sources.

There are three main ways of cross-contamination.

(a) Food to food
(b) People to food
(c) Equipment to food

Contamination of Plants

The internal cells and tissues of healthy plants are mainly sterile. The invasion of healthy tissues and subsequent growth of microorganisms can be prevented by:

(a) Outer mechanical barrier e.g., epidermis with outer waxy and corky layers.
(b) Chemical constituents that are anti-microbial e.g., tannins, organic acids and essential oils.
(c) Inert wall in tissues that is difficult to penetrate.
(d) Active cells with intact membranes.

Plant material is harvested in healthy condition and as long as the mechanical barrier is intact they can be stored at low temperature for several months without damage.

Contamination of Animals

In animals, skin, intestine, mouth, lymph nodes and liver can also be invaded by microorganisms. The invasion of healthy tissue and subsequent growth of microorganisms can be prevented by:

(a) Epithelial barriers e.g., stratified skin epithelium (epidermis) and intestinal mucosa.
(b) The immune system consisting of lymphatic system, white blood cells and antibodies.
(c) Active cells with intact membranes.
(d) Presence of natural antimicrobials e.g., lysozyme in tears, saliva.
(e) Voiding mechanism such as vomiting.

Sources of Food Contamination

There are five major events that can cause food contamination:

(a) **Food production:** The use of chemicals, fertilizers and manures has the potential to contaminate food as it is being grown.
(b) **Food processing:** The food processing area can be a major source of contamination. Areas used for processing need to be kept clean or cross-contamination can occur especially with meat products (natural bacteria residing in the intestines of animals are a major source of cross-contamination).
(c) **Food storage:** Food that is not properly stored, for instance, uncooked chicken resting next to a bunch of fruits can be a source of bacteria and other contaminants from one food to another.

(d) **Food preparation:** A great deal of food contamination occurs during the preparation stage. A chopping board used for meat that is not washed and used for vegetables is another source of possible contamination. Unwashed hands, dirty kitchen space, insects and rodents in the kitchen etc. are all possible sources of food contamination.

(e) **Environmental factors:** Bacterial parasites, fungal spores, etc. travel in the wind, float on water, deposited with dust and reside in the soil. They are a part of nature and will always be a possible source of contamination if not dealt appropriately as part of a consistent and dedicated approach to food hygiene.

Conclusion

Food contaminations and spoilage make food and food products unsuitable for consumption. The possibility and extent of spoilage is influenced by various external and internal factors, the type of food, packaging and storage conditions. It is estimated that one-third of the worlds' food produced is lost every year due to contamination and spoilage. Bacteria, fungi, improper packaging, mishandling and improper storage are the causes of spoilage that can create serious consequences, but there are preventative measures that can be taken to avoid or delay contamination and spoilage.

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