1

Food Preservation: Overview

Mohammad Shafiur Rahman

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1.1 Introduction

Food preservation involves the action taken to maintain foods with the desired properties or nature for as long as possible. The process is now moving from an art to a highly interdisciplinary science. This chapter provides an overview of food preservation methods with emphasis on inactivation, inhibition, and methods of avoiding recontamination. The final section is a discussion of the factors that need to be considered to satisfy present and future demands of the consumers and law-enforcing authorities.

In most countries, innovation, sustainability, and safety have become the main foci of modern industry and economy. The United Nations World Commission on Environment and Development defined sustainable development as "meeting the needs of the present generation without compromising the ability of future generations to meet their own needs." A sustainable way of designing and developing food products stands to appeal to consumers, and provides a point of differentiation from competitors and a perfect platform for a range of positive public relations activities [6]. Innovation is vital to maintain progress in technology and engineering. Food safety is now the first priority of the food production and preservation industry, incorporating innovation and sustainability. The industry can compromise with some quantities such as color to some extent, but not with safety.

The preservation and processing of food is not as simple or straightforward as it was in the past. A number of new preservation techniques are being developed to satisfy current demands of economic preservation and consumer satisfaction in nutritional and sensory aspects, convenience, safety, absence of chemical preservatives, price, and environmental safety. Understanding the effects of each preservation method on food has therefore become critical in all aspects. This chapter provides overviews of the new technology, identifying the changing demands of food quality, convenience, and safety.

1.2 What Are Foods?

Foods are materials, raw, processed, or formulated, that are consumed orally by humans or animals for growth, health, satisfaction, pleasure, and satisfying social needs. Generally, there is no limitation on the amount of food that may be consumed (as there is for a drug in the form of dosage) [10]. This does not mean that we can eat any food item as much as we want. Excessive amounts could be lethal, for example, salt, fat, and sugar. Chemically, foods are mainly composed of water, lipids, fat, and carbohydrate with small proportions of minerals and organic compounds. Minerals include salts and organic substances include vitamins, emulsifiers, acids, antioxidants, pigments, polyphenols, and flavor-producing compounds [19]. The different classes of foods are perishable, nonperishable, harvested, fresh, minimally processed, preserved, manufactured, formulated, primary, secondary derivatives, synthetic, functional, and medical foods [21]. The preservation method is mainly based on the types of food that need to be prepared or formulated.

1.3 Food Preservation

Preservation methods start with the complete analysis and understanding of the whole food chain, including growing, harvesting, processing, packaging, and distribution; thus an integrated approach needs to be applied. It lies at the heart of food science and technology, and it is the main purpose of food processing. First, it is important to identify the properties or characteristics that need to be preserved. One property may be important for one product, but detrimental for others. For example, collapse and pore formation occur during the drying of foods. This can be desirable or undesirable depending on the desired quality of the dried product, for example, crust formation is desirable for long bowl life in the case of breakfast cereal ingredients, and quick rehydration is necessary (i.e., no crust and more open pores) for instant soup ingredients. In another instance, the consumer expects apple juice to be clear whereas orange juice could be cloudy.

1.3.1 Why Preservation?

Another important question is *why* food needs to be preserved. The main reasons for food preservation are to overcome inappropriate planning in agriculture, produce value-added products, and provide variation in diet [20]. The agricultural industry produces raw food materials in different sectors. Inadequate management or improper planning in agricultural production can be overcome by avoiding inappropriate areas, times, and amounts of raw food materials as well as by increasing storage life using simple methods of preservation. Value-added food products can give better-quality foods in terms of improved nutritional, functional, convenience, and sensory properties. Consumer demand for healthier and more convenient foods also affects the way food is preserved. Eating should be pleasurable to the consumer, and not boring. People like to eat wide varieties of foods with different tastes and flavors. Variation in the diet is important, particularly in underdeveloped countries to reduce reliance on a specific type of grain (i.e., rice or wheat). In food preservation, the important points that need to be considered are

- The desired level of quality
- The preservation length
- The group for whom the products are preserved

After storage of a preserved food for a certain period, one or more of its quality attributes may reach an undesirable state. Quality is an illusive, ever-changing concept. In general, it is defined as the degree of fitness for use or the condition indicated by the satisfaction level of consumers. When food has deteriorated to such an extent that it is considered unsuitable for consumption, it is said to have reached the end of its shelf life. In studying the shelf life of foods, it is important to measure the rate of change of a given quality attribute [25]. In all cases, safety is the first attribute, followed by other quality. The product quality attributes can be quite varied, such as appearance, sensory, or microbial characteristics. Loss of quality is highly dependent on types of food and composition, formulation (for manufactured foods), packaging, and storage conditions [25]. Quality loss can be minimized at any stage of food harvesting, processing, distribution, and storage. When preservation fails, the consequences range broadly from minor deterioration, such as color loss, to food becoming extremely hazardous [8].

1.3.2 How Long to Preserve?

After storage for a certain period, one or more quality attributes of a food may reach an undesirable state. At that time, the food is considered unsuitable for consumption and is said to have reached the end of its shelf life. This level is defined by the manufacturer according to criteria when the product is saleable. Best-before date is set shorter than the shelf life with a good margin. Hence, it is usually safe and palatable to consume a product a long time after the best-before date, provided the product has been stored at the recommended conditions. Products may be marketed with the production date "pack date" and "best-before date." Alternative markings are use-by date or expiration date, which may be closer to shelf life than best-before date [1]. In studying the shelf life of foods, it is important to measure the rate of change of a given quality attribute [25]. The product quality can be defined using many factors, including appearance, yield, eating characteristics, and microbial characteristics, but ultimately the final use must provide a pleasurable experience for the consumer [23]. The various stages of food production, manufacture, storage, distribution, and sale are shown in Figure 1.1. Quality loss can be minimized at any stage and thus quality depends on the overall control of the processing chain. The major quality-loss mechanisms and consequences are shown in Table 1.1 and Figure 1.2. The required length of preservation depends on the purpose. In many cases, very prolonged storage or shelf life is not needed, which simplifies both the transport and marketing of the foodstuff. For example, the meals prepared for lunch need a shelf life of only one or even half a day. In this case, there is no point in ensuring preservation of the product for weeks or months. In other cases, very long shelf life up to 3–5 years may be required, for example, foods for space travelers and food storage during wars.

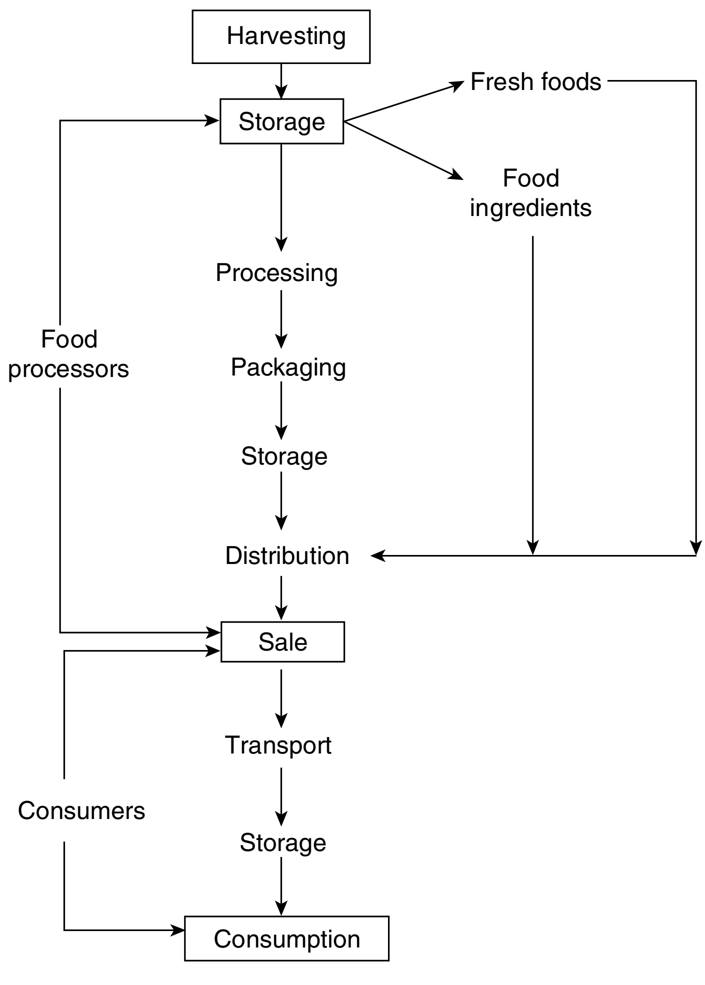

FIGURE 1.1 Various stages of food production, manufacture, storage, distribution, and sale.

1.3.3 For Whom to Preserve?

It is important to know for whom the preserved food is being produced. Nutritional requirements and food restrictions apply differently to different population groups. Food poisoning can be fatal, especially in infants, pregnant women, the elderly, and those with depressed immune systems. The legal aspects of food preservation are different

TABLE 1.1
Major Quality-Loss Mechanisms

Microbiological	Enzymatic	Chemical	Physical	Mechanical
Microorganism growth	Browning	Color loss	Collapse	Bruising due to vibration
Off-flavor	Color change	Flavor loss	Controlled release	Cracking
Toxin production	Off-flavor	Nonenzymatic browning	Crystallization	Damage due to pressure
		Nutrient loss	Flavor encapsulation	
		Oxidation–reduction	Phase changes	
		Rancidity	Recrystallization	
			Shrinkage	
			Transport of component	

Source: Gould, G. W. 1989. In: *Mechanisms of Action of Food Preservation Procedures*. Gould, G. W., Ed. Elsevier Applied Science, London; Gould, G. W. 1995. In: *New Methods of Food Preservation*. Gould, G. W., Ed. Blackie Academic and Professional, Glasgow.

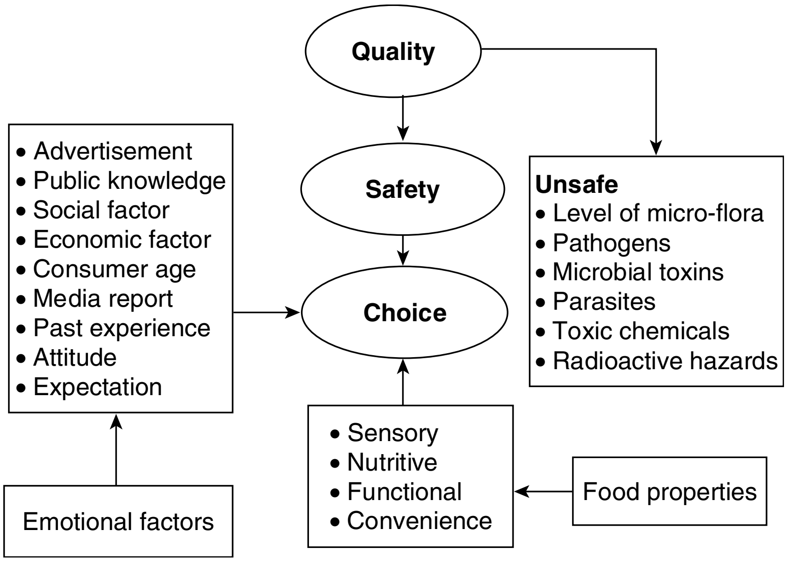

FIGURE 1.2 Factors affecting food quality, safety, and choice.

in case of foods produced for human and for animal consumption. Thus, it is necessary to consider the group for whom the products are being manufactured.

1.4 Causes of Deterioration

Mechanical, physical, chemical, and microbial effects are the leading causes of food deterioration and spoilage. Damage can start at the initial point by mishandling of foods during harvesting, processing, and distribution; this may lead to ultimate reduction of shelf life. Other examples of deterioration can be listed as follows: (i) bruising of fruits and vegetables during harvesting and postharvest handing, leading to the development of rot, (ii) tuberous and leafy vegetables lose water when kept in atmospheres with low humidity and, subsequently, wilt, and (iii) dried foods kept in high humidity may pick up moisture and become soggy. The four sources of microbial contaminants are soil, water, air, and animals (insects, rodents, and humans) (Table 1.2). The major causes of quality loss are shown in Table 1.1. In preservation, each

TABLE 1.2

Organisms That Spoil Foods

1. Microorganisms
   a. Fungi: mold and yeast
   b. Bacteria
   c. Phages
   d. Protozoa
2. Insects and mites
   a. Directly by eating (infestation)
   b. Indirectly by spreading diseases (fruitfly, housefly)
3. Rodents
   a. Directly by consuming food
   b. Indirectly by spreading diseases

Source: Borgstrom, G. 1968. *Principles of Food Science.* Macmillan, London.

TABLE 1.3

Storage Life of Some Fresh Foods at Normal Atmospheric Conditions

Food	Terminology	Storage Life
Meat, fish, and milk	Perishable	1–2 days
Fruits and vegetables	Semiperishable	1–2 weeks
Root crops	Semiperishable	3–4 weeks
Grains, pulses, seeds, and nuts	Nonperishable	12 Months

Source: Rahman, M. S. 1999. In: *Handbook of Food Preservation.* Rahman, M. S., Ed. Marcel Dekker, New York. pp. 1–9.

factor needs to be controlled or maintained to a desired level. Foods are perishable or deteriorative by nature. The storage life of fresh foods under normal atmospheric conditions is presented in Table 1.3.

During storage and distribution, foods are exposed to a wide range of environmental conditions. Environmental factors such as pressure, temperature, humidity, oxygen, and light can trigger several reactions that may lead to food degradation. As a consequence of these mechanisms, foods may be altered to such an extent that they are either rejected by or harmful to the consumer [25]. Condensation of moisture on foods or a damp atmosphere favors microbial growth, occasionally promotes insects development, and may indirectly lead to deterioration, resulting in destructive self-heating [3]. Mechanical damage (e.g., bruises and wounds) is conducive to spoilage, and it frequently causes further chemical and microbial deterioration. Peels, skins, and shells constitute natural protection against this kind of spoilage [3]. In case of frozen foods, fluctuating temperatures are often destructive, for example, fluctuating temperatures cause recrystallization of ice cream, leading to an undesirable sandy texture. Freezer burn is a major quality defect in frozen foods that is caused by the exposure of frozen foods to fluctuating temperatures. These large fluctuations may cause a phase change by thawing or refreezing foods. Similarly, phase changes involving melting and solidifying of fats are detrimental to the quality of candies and other lipid-containing confectionary items. Shriveling occurs due to the loss of water from harvested fruits and vegetables.

Each microorganism has (i) an optimum temperature at which it grows best, (ii) a minimum temperature below which growth no longer takes place, and (iii) a maximum temperature above which all development is suppressed. Bacteria that grow particularly well at low temperatures are called *psychrophilic* (*cryophilic*) or low-temperature organisms. Bacteria with an optimum temperature of 20°C–45°C are *mesophilic*, and those with an optimum temperature above 45°C are *thermophilic* [3]. Microbial growth in foods results in food spoilage with the development of undesirable sensory characteristics, and in certain cases the food may become unsafe for consumption. Microorganisms have the ability to multiply at high rates when favorable conditions are present. Prior to harvest, fruits and vegetables generally have good defense mechanisms against microbial attack; however, after separation from the plant, they can easily succumb to microbial proliferation. Similarly, meat upon slaughter is unable to resist rapidly growing microbes [25]. The pathogenicity of certain microorganisms is a major safety concern in the processing and handling of foods in that they produce chemicals in foods that are toxic to humans. Their growth on foods may also result in undesirable appearances and off-flavors. Microbial or chemical contaminants are also of concern in food deterioration. Chemicals from packaging materials may also be a source of food contamination.

Several chemical changes occur during the processing and storage of foods. These changes may cause food to deteriorate by reducing its sensory and nutritional quality. Many enzymatic reactions change the quality of foods. For example, fruits when cut tend to brown rapidly at room temperature due to the reaction of phenolase with cell constituents released in the presence of oxygen. Enzymes such as lipooxygenase, if not denatured during the blanching process, can influence food quality even at subfreezing temperatures. In addition to temperature, other environmental factors such as oxygen, water, and pH induce deleterious changes in foods that are catalyzed by enzymes [25].

The presence of unsaturated fatty acids in foods is a prime reason for the development of rancidity during storage as long as oxygen is available. While development of off-flavors is markedly noticeable in rancid foods, the generation of free radicals during the autocatalytic process leads to other undesirable reactions, for example, loss of vitamins, alteration of color, and degradation of proteins. The presence of oxygen in the immediate vicinity of food leads to increased rates of oxidation. Similarly, water plays an important role; lipid oxidation occurs at high rates at very low water activities.

Some chemical reactions are induced by light, such as loss of vitamins and browning of meats. Nonenzymatic browning is a major cause of quality change and degradation of the nutritional content of many foods. This type of browning reaction occurs due to the interaction between reducing sugars and amino acids, resulting in the loss of protein solubility, darkening of lightly colored dried products, and development of bitter flavors. Environmental factors such as temperature, water activity, and pH have an influence on nonenzymatic browning [25].

1.5 Food Preservation Methods

Based on the mode of action, the major food preservation techniques can be categorized as (1) slowing down or inhibiting chemical deterioration and microbial growth, (2) directly inactivating bacteria, yeasts, molds, or enzymes, and (3) avoiding recontamination before and after processing [8,9]. A number of techniques or methods from the above categories are shown in Figure 1.3. While the currently used traditional preservation procedures continue in one or more of these three ways, there have recently been great efforts to improve the quality of food products principally to meet the requirements of consumers through the

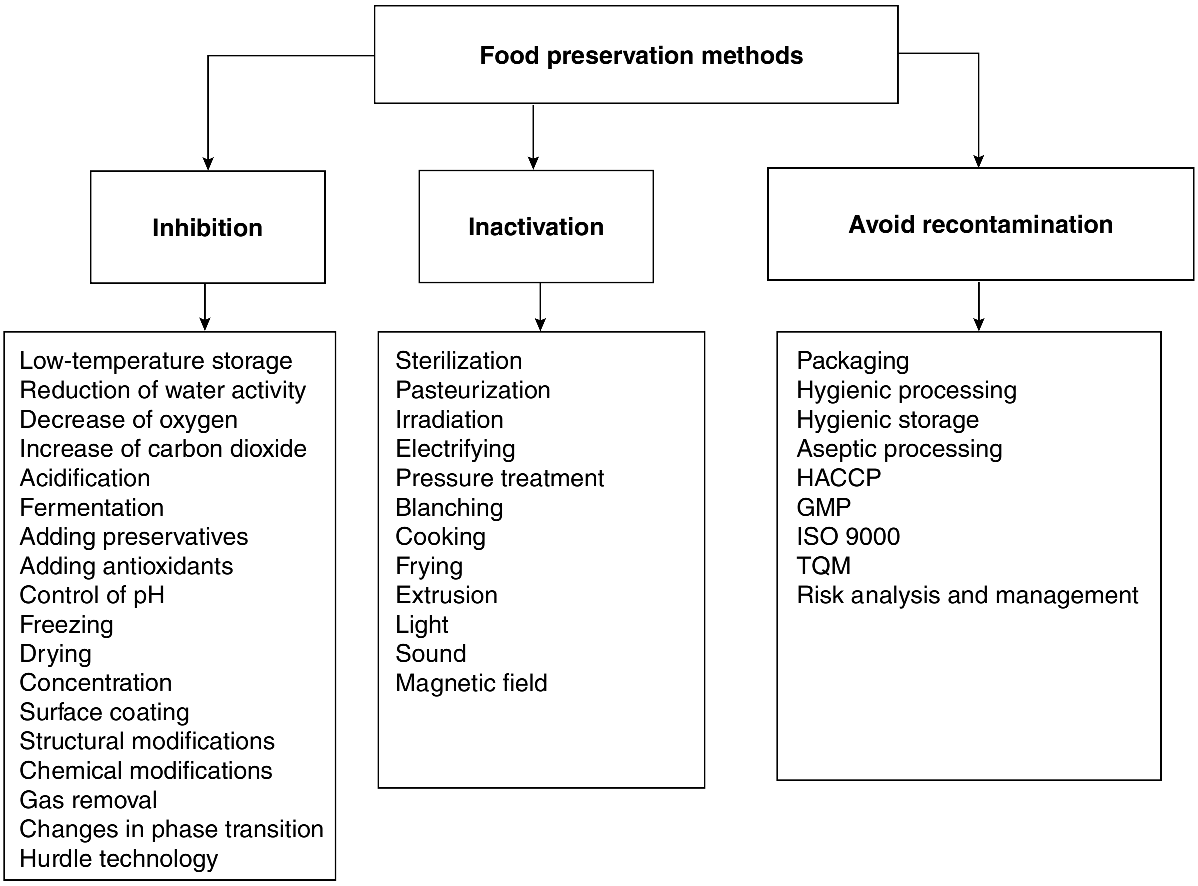

FIGURE 1.3 Major food preservation techniques. (From Gould, G. W. 1989. In: *Mechanisms of Action of Food Preservation Procedures*. Gould, G. W., Ed. Elsevier Applied Science, London; Gould, G. W. 1995. In: *New Methods of Food Preservation*. Gould, G. W., Ed. Blackie Academic and Professional, Glasgow.)

avoidance of extreme use of any single technique. Preservation starts when the harvested foods are separated from the medium of immediate growth (plant, soil, or water) or meat from the animal after slaughter, or milk from normal secretion of mammalian glands. Raw foods are those in the earliest or primary state after harvesting, milking, or slaughter; they have not been subjected to any treatment apart from cleaning and size grading in the case of foods of plant origin. Postharvest technology is concerned with handling, preservation, and storage of harvested foods, and maintaining its original integrity, freshness, and quality. The methods of preservation depend on the origin of foods—particularly whether they are of plant or animal origin. Postharvest handling of foods of plant origin includes efficient control of environmental atmosphere, such as humidity, gas composition, and temperature, and implementing an adequate packing, storage, and transport system. Physical treatments usually used are curing, precooling, temperature treatments, cleaning, and waxing, whereas chemical treatments are disinfection, fumigation, and dipping. Meat is the edible flesh of a number of species of mammal or bird, both wild and domesticated. Postharvest quality is affected by slaughter conditions or stress before death.

In the case of fish, preservation methods include chilling, electrical stimulation, and decontamination methods, for example, hot water rinsing with or without chlorination, decontamination with phosphate, hydrogen peroxide, chlorine, chlorine dioxide and ozone, and surface treatment by organic acids. Pretreatments, such as blanching, sulfiting, and other physical and chemical pretreatments are used before applying major preservations methods. The main purpose of pretreatment is to improve product quality and process efficiency. In recent years, altering processing strategy and pretreatment has gained much attention in the food industry.

The steps of cleaning and sanitization are important in food preservation. Chemical disinfectants vary in their ability to kill microorganisms. Effectiveness depends on the types of microorganisms, their attachment mechanisms, and physical characteristics of the produce. Some disinfectants are appropriate for use in direct-contact washes; others only for processing water, processing equipment or containers and facilities. It is important to know the effectiveness of the mechanisms of action of disinfectants, as well as the relevant microbial biochemistry. Several chemicals are utilized, such as chlorine, chlorine dioxide, hydrogen peroxide, ozone, peroxyacetic acid, bromine, iodine, trisodium phosphate, and quaternary ammonium compounds [5]. Although fumigants are not strictly preservatives, they are used for insect control. Methyl bromide is one of the fumigants used, but it has the potential to damage atmospheric ozone and is being phased out. There is a need for development of new environmentally safe methods of fumigation.

1.5.1 Inhibition

The methods based on inhibition include those that rely on control of the environment (e.g., temperature control), those that result from particular methods of processing (e.g., microstructural control), and those that depend on the intrinsic properties built into particular foods (e.g., control by the adjustment of water activity or pH value [9]. The danger zone for microbial growth is considered to be between 5°C and 60°C; thus chilling and storing at a temperature below 5°C is one of the most popular methods of food preservation.

1.5.2 Use of Chemicals

The use of chemicals in foods is a well-known method of food preservation. Wide varieties of chemicals or additives are used in food preservations to control pH, as antimicrobes and antioxidants, and to provide food functionality as well as preservation action. Some additives are entirely synthetic (not found in nature), such as phenolic antioxidant tertiary butylhydroquinone (TBHQ), and others are extracted from natural sources, such as vitamin E. Irrespective of origin, food additives must accomplish some desired function in the food to which they are added, and they must be safe to consume under the intended conditions of use.

Many legally permitted preservatives in foods are organic acids and esters, including sulfites, nitrites, acetic acid, citric acid, lactic acid, sorbic acid, benzoic acid, sodium diacetate, sodium benzoate, methyl paraben, ethyl paraben, propyl paraben, and sodium propionate [24]. When a weak acid is dissolved in water, equilibrium is established between undissociated acid molecules and charged anions, the proportion of undissociated acid increasing with decreasing pH. The currently accepted theory of preservative action suggests inhibition via depression of internal pH. Undissociated acid molecules are lipophilic and pass readily through the plasma membrane by diffusion. In the cytoplasm, approximately at pH 7.0, acid molecules dissociate into charged anions and protons. These cannot pass across the lipid bilayer and accumulate in cytoplasm, thus lowering pH and inhibiting metabolism [14]. There are several limitations to the value of organic acids as microbial inhibitors in foods:

- They are usually ineffective when initial levels of microorganisms are high.
- Many microorganisms use organic acids as metabolizable carbon sources.
- There is inherent variability in resistance of individual strains.
- The degree of resistance may also depend on the conditions [24].

Nitrides and nitrates are used in many foods as preservatives and functional ingredients. These are critical components used to cure meat, and they are known to be multifunctional food additives and potent antioxidants. Many plants contain compounds that have some antimicrobial activity, collectively referred to as "green chemicals" or "biopreservatives" [26]. Interest in naturally occurring antimicrobial systems has expanded in recent years in response to consumers' requirements for fresher, more natural additive-free foods [9]. A range of herbs and spices are known to possess antibacterial activity as a consequence of their chemical composition. Antimicrobial agents can occur in foods of both animal and vegetable origin. Herbs and spices have been used for centuries by many cultures to improve the flavor and aroma of foods. Essential oils show antimicrobial properties, and are defined by Hargreaves as a group of odorous principles, soluble in alcohol and to a limited extent in water, consisting of a mixture of esters, aldehydes, ketones, and terpenes. They not only provide flavor to the product, but also preservation activity. Scientific studies have identified the active antimicrobial agents of many herbs and spices. These include eugenol in cloves, allicin in garlic, cinnamic aldehyde and eugenol in cinnamon, allyl isothiocyanate in mustard, eugenol and thymol in sage, and isothymol and thymol in oregano [15].

Rancidity is an objectionable defect in food quality. Fats, oils, or fatty foods are deemed rancid if a significant deterioration of the sensory quality is perceived, particularly aroma or flavor, but appearance and texture may also be affected. Antioxidants are used to control oxidation in foods, and they also have health functionality by reducing risk of cardiovascular diseases and cancer, and slowing down the aging process. The use of wood smoke to preserve foods is nearly as old as open-air drying. Although not primarily used to reduce the moisture content of food, the heat associated with the generation of smoke also gives a drying effect. Smoking has been mainly used with meat and fish. Smoking not only imparts desirable flavor and color to some foods, but some of the compounds formed during smoking also have a preservative effect (bactericidal and antioxidant).

Hydrogen ion concentration, measured as pH, is a controlling factor in regulating many chemical, biochemical, and microbiological reactions. Foods having a pH < 4.5 are considered as low-risk foods; they need less severity in heat treatment. Microorganisms require water, nutrients, appropriate temperature, and pH levels for growth. Below an approximate pH of 4.2 most other food-poisoning microorganisms are well controlled, but microorganisms such as lactic acid bacteria and many species of yeast and molds grow at pH values well below this. Many weak lipophilic organic acids act synergistically at low pH to inhibit microbial growth. Thus, propionic, sorbic, and benzoic acids are very useful food preservatives. The efficacy of acids depends to a large extent on their ability to equilibrate, in their undissociated forms, across the microbial cell membrane and in doing so, interferes with the pH gradient that is normally maintained between the inside (cytoplasm) of the cell and the food matrix surrounding it. In addition to weak lipophilic acids, other preservatives widely used in foods include esters of benzoic acid, which are effective at higher pH values than organic acids. Inorganic acids, such as sulfate and nitrite, are most effective at reduced pH values, like organic acids. While these preservatives are employed at ppm levels of hundreds to thousands, the acids used principally as acidulants are often employed at percentage levels. The three regimes of pH actions are [2]

- Strong acids do not themselves penetrate the cell membrane. These acids may exert their influence by the denaturing effect of low pH on enzymes present on the cell surface and by lowering of the cytoplasmic pH due to increased proton permeability when the pH gradient is very large.

- Weak acids are lipophilic and penetrate the membrane. The primary effect of such acids is to lower cytoplasmic pH and undissociated acids may have specific effects on metabolism that amplify the effects of the weak acid.
- Acid-potentiated ions, such as carbonate, sulfate, and nitrate, which are inhibitors at lower pH.

The pH affects not only the growth of microorganism but also other components and processes, such as enzyme stability, gel formation, and stability of proteins and vitamins [20]. Antimicrobial enzymes also have current applications and further future potential in the food industry. They play a significant role in the defense mechanisms of living organisms against infection by bacteria and fungi. Many lytic enzymes now used in the food industry to degrade unwanted polysaccharides have potential for use as novel and natural food preservatives. One such enzyme, lysozyme from hen egg whites, has been known for many years and is used against clostridial spoilage in hard cooked cheese in France [22]. When enzymes are used, it is very important to maintain its activity for its effect in preservation. Hydrolytic antimicrobial enzymes function by degrading key structural components of the cell walls of bacteria and fungi, whereas antimicrobial oxidoreductases exert their effects by the *in situ* generation of reactive molecules. Fuglsang et al. [7] pointed that the potential of these enzymes in food preservation is still far from realized at present.

Antibiotics could be medical and nonmedical. Nonmedical antibiotics, such as natamycin and nisin, produced either by microbes or synthetically, inhibit microbes at very low concentration. Organisms present in food can become resistant to antibiotics and colonize the gut of animals and man. Antibiotics used therapeutically may then become ineffective. Also, antibiotics are used in growth enhancement and disease control in healthy animals. However, the increasing incidence of antibiotic resistance is of great concern and is becoming a complicated issue.

When a chemical is used in preservation, the main question is *how safe is it*? There should be a risk–benefit analysis. Antimicrobial agents or preservatives are diverse in nature, but legal, toxicological, marketing, and consumer considerations have created a trend such that both the number and amount of preservatives in use are diminishing rather than increasing [7].

1.5.3 Controls of Water and Structure

Many physical modifications are made in ingredients or foods during preservation. Such modifications can also improve the sensory, nutritional, and functional properties of foods. Changes experienced by foods during processing include glass formation, crystallization, caking, cracking, stickiness, oxidation, gelatinization, pore formation, and collapse. Through precise knowledge and understanding of such modifications, one can develop safe, high-quality foods for consumption [20].

Water is an important constituent of all foods. Scott in 1953 clearly identified that the activity of water as a medium is clearly correlated with the deterioration of food stability due to the growth of microorganisms and for stability this is more important than the total amount of water. This concept helps us to develop generalized rules or limits for stability of foods using water activity. This was the main reason why food scientists started to emphasize water activity rather than water content. Since then the scientific community has explored the great significance of water activity in determining the physical characteristics, processes, shelf life, and sensory properties of foods. The minimum water activity is the limit below which a microorganism or group of microorganisms can no longer reproduce. For most foods, this is in the water activity range of 0.6–0.7. Pathogenic bacteria cannot grow below a water activity of 0.85–0.86, whereas yeast and molds are more tolerant of a reduced water activity of 0.80, but usually no growth occurs below a water activity of about 0.62. The critical limits of water activity may also be shifted to higher or lower levels by other factors, such as pH, salt, antimicrobial agents, heat treatment, and temperature to some extent. Removing water, adding solutes, or change of solute–water interactions can reduce the water activity of a food.

Drying is one of the oldest methods of food preservation, where water activity is reduced by separating out water. Drying in earlier times was done under the sunlight, but today many types of sophisticated equipment and methods are being used to dehydrate foods—huge varieties of drying methods are now available. Drying is a method of water removal to form final products as solids, while concentration means the removal of water while retaining the liquid condition. The loss of flavor, aroma, or functional compounds is the main problem with drying, in terms of quality. The cost of processing, packaging, transportation, and storage is less for dried products than canned and frozen foods. The concentration of liquid foods is mainly carried out by thermal evaporation, freeze concentration, and membrane separation. Each method has its advantages and disadvantages.

Freezing changes the physical state of a substance by changing water into ice when energy is removed in the form of cooling below freezing temperature. Usually, the temperature is further reduced to storage level at –18°C. Microbial growth is completely stopped below –18°C, and both enzymatic and nonenzymatic changes continue at much slower rates during frozen storage. There is a slow progressive change in organoleptic quality during storage. Freezing is more popular than drying due to its ability to retain more fresh-like qualities in the food.

Foods can be considered very stable in the glassy state since below glass temperature compounds involved in deterioration reactions take months or even years to diffuse over molecular distances and approach each other to react. The hypothesis has recently been stated that this transition greatly influences food stability, as the water in the concentrated phase becomes kinetically immobilized and therefore does not support or participate in reactions. Formation of a glassy state results in a significant arrest of translational molecular motion, and chemical reactions become very slow. Many attempts are being made to relate the glass concept to physicochemical changes in foods.

Edible coatings serve many purposes in food systems. Coatings are used to improve appearance or texture and reduce water loss. Examples include the waxing of apples and oranges to add gloss, waxing of frozen fish to add gloss and reduce shrinkage due to water loss, or coating of candies to reduce stickiness. Other surface treatments for foods include application of antioxidants, acidulants (or other pH-control agents), fungicides, preservatives, and mineral salts. The formulation of edible coatings depends on the purpose and type of products. Encapsulation has been used by the food industry for more than 60 years. In a broad sense, encapsulation technology in food processing includes the coating of minute particles of ingredients (e.g., acidulants, fats, and flavors) as well as whole ingredients (e.g., raisins, nuts, and confectionery products), which may be accomplished by microencapsulation and macrocoating techniques.

Gums and gels, such as casein, guar gum, agar, carrageenan, and pectin, are also used in food products to provide desired structure and functionality to the products. These are extremely important for the textural attributes, such as creaminess and oiliness of formulated products, and fat-mimic foods.

1.5.4 Control of Atmosphere

Packaging techniques based on altered gas compositions have a long history. The respiratory activity of the various plant products generates a low-oxygen and high-carbon dioxide atmosphere, which retards the ripening of fruit. Modified-atmosphere packaging is a preservation technique that may further minimize the physiological and microbial decay of perishable produce by keeping them in an atmosphere that is different from the normal composition of air. The gas composition and method of this technique depends on the types of produce and purposes. There are different ways of maintaining a modified atmosphere. In modified-atmosphere packaging (termed "passive atmosphere"), the gas composition within the package is not monitored or adjusted. In "controlled atmosphere packaging," the altered gas composition inside the packaging is monitored and maintained at a preset level by means of scrubbers and the inlet of gases. Active packaging can provide a solution by adding materials that absorb or release a specific compound in the gas phase. Compounds that can be absorbed are carbon dioxide, oxygen, water vapor, ethylene, or volatiles that influence taste and aroma. Vacuum and modified-humidity packaging contain a changed atmosphere around the product. Although this technique was initially developed to extend the shelf life of fresh products, it is now extended to minimally processed foods from plant and animal sources, and also to dried foods.

1.5.5 Inactivation

1.5.5.1 Use of Heat Energy

Earlier, mostly heat was used for inactivation. Thermal inactivation is still the most widely used process of food preservation. The advantages of using heat for food preservation are

- Heat is safe and chemical-free
- It provides tender cooked flavors and taste
- The majority of spoilage microorganisms are heat labile
- Thermally processed foods, when packed in sterile containers, have a very long shelf life

The main disadvantages of using heat are (i) overcooking may lead to textural disintegration and an undesirable cooked flavor, and (ii) nutritional deterioration results from high temperature processing. Heat treatment processes include mainly pasteurization, sterilization, cooking, extrusion, and frying. Recently, more electrotechnologies have been used and this will expand further in the future.

1.5.5.2 Use of High Pressure and Ultrasound

High-quality fresh foods are very popular, so consequently there is a demand for less extreme treatments and fewer additives. High-pressure hydrostatic technology gained attention for its novelty and nonthermal preservation effect. Studies examining the effects of high pressure on food date back to the end of the nineteenth century, but renewed research and commercialization efforts worldwide could soon bring high-pressure-treated foods back to several markets. The basis of high hydrostatic pressure is the Le Chatelier's principle, according to which any reaction, conformational change, or phase transition that is accompanied by a decrease in volume will be favored at high pressures, while reactions involving an increase in volume will be inhibited. Predictions of the effects of high-pressure treatments on foods are difficult to generalize due to the complexity of foods and the different changes and reactions that can occur. However, a tremendous amount of information is being developed on microbial, chemical, biochemical, and enzymatic reactions, development of functional and sensory properties, gel formation, gelatinization, and freezing process.

Ultrasound is sound energy with a frequency range that covers the region from the upper limit of human hearing, which is generally considered to be 20 kHz. The two applications of ultrasound in foods are (i) characterizing a food material or process, such as estimation of chemical composition, measurements of physical properties, nondestructive testing of quality attributes, and monitoring food processing, and (ii) direct use in food preservation or processing. The beneficial or deteriorative use of ultrasound depends on its chemical, mechanical, or physical effects on the process or products.

1.5.5.3 Use of Electricity

Many different forms of electrical energy are used in food preservation, e.g., ohmic heating, microwave heating, low electric field stimulation, high-voltage arc discharge, and high-intensity pulsed electric field. *Ohmic heating* is one of the earliest forms of electricity applied to food pasteurization. This method relies on the heat generated in food products as a result of electrical resistance when an electric current is passed through them. In conventional heating methods, heating travels from a heated surface to the product interior by means of both convection and conduction, which is time consuming, especially with longer convection or conduction paths. Electroresistive or ohmic heating is volumetric by nature and thus has potential to reduce overprocessing. It provides rapid and even or uniform heating, providing less thermal damage and increased energy efficiency. *Microwave heating* has been extensively applied in everyday households and the food industry, but the low penetration depth of microwaves into solid food causes thermal nonuniformity. *Low electric field* stimulation has been explored as a method of bacterial control in meat. The mechanism of microbial inactivation by electric field was first proposed by Pareilleux and Sicard [16]. The plasma membranes of cells become permeable to small molecules after being exposed to an electric field; permeation then causes swelling and the eventual rupture of the cell membrane. The reversible or irreversible rupture (or electroporation) of a cell wall membrane depends on factors such as intensity of the electric field, number of pulses, and duration of pulses. This new electroheating could be used to develop new products with diversified functionality.

1.5.5.4 Use of Radiation

Ionization radiation interacts with an irradiated material by transferring energy to electrons and ionizing molecules by creating positive and negative ions. The irradiation process involves exposing the foods, either prepackaged or in bulk, to a predetermined level of ionization radiation. The radiation effects on biological materials are direct and indirect. In direct action, the chemical events occur as a result of energy deposition by the radiation in the target molecule, and the indirect effects occur as a consequence of reactive diffusible free radicals formed from the radiolysis of water, such as the hydroxyl radical (OH^-), a hydrated electron (e_{aq}^-), a hydrogen atom, hydrogen peroxide, and hydrogen. Hydrogen peroxide is a strong oxidizing agent and a poison to biological systems, while the hydroxyl radical is a strong oxidizing agent and the hydrogen radical a strong reducing agent. Irradiation has wide scope in food disinfection, shelf life extension, decontamination, and product quality improvement. Although it has high potential, there is concern on legal aspects and safety issues, and consumer attitude toward this technology.

Ultraviolet (UV) radiation has long been known to be the major factor in the antibacterial action of sunlight. It is mainly used in sterilizing air and thin liquid films due to its low penetration depth. When used at high dosage, there is a marked tendency toward flavor and odor deterioration before satisfactory sterilization is achieved. UV irradiation is safe, environment friendly, and more cost-effective to install and operate than conventional chlorination. Visible light and photoreactivation are also used in food processing. If microorganisms are treated with dyes, they may become sensitive to damage by visible light. This effect is known as photoreactivation. Some food ingredients could induce the same reaction. Such dyes are said to possess photodynamic action. White and UV light are also used to inactivate bacteria, fungi, spores, viruses, protozoa, and cysts. Pulsed light is a sterilization method in applications where light can access all the important volume and surfaces. Examples include packaging materials, surfaces, transmissive materials (such as air, water, and many solutions), and many pharmaceuticals or medical products. The white light pulse is generated by electrically ionizing a xenon gas-filled lamp for a few hundred millionths of a second with a high-power, high-voltage pulse.

In many cases, it would be very difficult to make a clear distinction between inhibition and inactivation. Take, for example, preservation by drying and freezing. Although the main purpose of freezing and drying is to control the growth of microorganisms, there is also some destruction of microorganisms. Freezing causes the apparent death of 10%–60% of the viable microbial population and this gradually increases during storage.

1.5.5.5 Use of Magnetic Field

Magnetism is a phenomenon by which materials exert an attractive or repulsive force on other materials. The origin of magnetism lies in the orbital and spin motions of electrons and how the electrons interact with each other. Magnetic fields have potential in pasteurization, sterilization, and enhancing other factors beneficial to processing in food preservation.

1.5.6 Avoid Recontamination (Indirect Approach)

In addition to the direct approach, other measures such as packaging and quality management tools need to be implemented in the preservation process to avoid contamination or recontamination. Although these measures are not preservation techniques, they play an important role in producing high-quality safe food. With respect to the procedures that restrict the access of microorganisms to foods, the employment of aseptic packaging techniques for thermally processed foods has expanded greatly in recent years both in the numbers of applications and in the numbers of alternative techniques that are commonly available [9].

From skins, leaves, and bark, tremendous progress has been made in the development of diversified packaging materials and equipments. Packaging performs three main functions. The first is to control the local environmental conditions to enhance storage life. The second is the display, i.e., preservation of the product in an attractive manner to the potential buyer. The third function is to protect the product during transit to the consumer. The new concept of active or life packaging materials allows one-way transfer of gases away from the product or the absorption of gases detrimental to the product, antimicrobials in packaging, release of preservatives from controlled-release surfaces, oxygen scavengers, carbon dioxide generators, absorbers or scavengers of odors, absorption of selected wavelengths of light, and there are capabilities for controlled automatic switching. Another concept of edible or biodegradable packaging has also been evolved for environmental reasons. Processing and packaging can be integrated to improve efficiency.

Food safety has been of concern since the Middle Ages, and regulatory measures have been enforced to prevent the sale of adulterated or contaminated food. Food safety is now the highest priority. Recently, the concepts of Hazard Analysis and Critical Control Point (HACCP), ISO 9000, Good Manufacturing Practices (GMP), Standard Operating Procedures (SOP), Hazard and Operability Studies (HAZOP), and Total Quality Management (TQM) have gained attention. HACCP is a state-of-the-art prevention approach to safe food production based on prevention and documentation, and is thus cost-effective. It is a proactive approach based on science. Most of the food industry around the globe is now targeting the implementation of HACCP programs for their processes to ensure safety. HACCP is a scientific, rational, and systematic approach to identification, assessment, and control of hazards during production, processing, manufacturing, preparation, and use of food to ensure that it is safe when consumed. This concept is based on the application of prevention and documentation. The HACCP system provides a preventive and thus a cost-effective approach to food safety. It is important to understand the concept of safety and quality first before planning to implement HACCP in the branch of the food industry or the products being targeted. The concepts of HACCP were initiated in the 1950s by the National Aeronautics and Space Administration (NASA) and the Natick Laboratories for use in aerospace manufacturing. This rational approach to process control for food products was developed jointly by the Pillsbury Company, NASA, and US Army Natick Laboratories in 1971 to apply a zero-defects program to the food process industry [14,17]. The World Health Organization (WHO) has recognized the importance of the HACCP system for the prevention of food-borne diseases for over 20 years and has played an important role in its development and promotion. One of the highlights in the history of the HACCP system was in 1993 when the Codex guidelines for the application of the HACCP system were adopted by the FAO/WHO Codex Alimentarius Commission, requiring them for international trade.

ISO 9000 is the generic standard that specifies minimum requirements to be fulfilled by organizations to meet a customer's needs. It does not specifically address the issue of food safety, but it addresses the need to identify and comply with regulatory requirements that are applicable to the product and process. ISO 9000 standard and HACCP techniques are complementary. HACCP techniques should therefore be used as a tool to support the quality management system ISO 9000.

To meet the requirements of GMP, regulatory bodies provided well-defined guidelines for food processing operations. GMP could be considered as the building blocks and cornerstones of the HACCP. TQM is a management philosophy that seeks continuous improvement in the quality of performance of all processes, products, and services of an organization. HAZOP is a systematic structured approach to questioning the sequential stages of a proposed operation to optimize the efficiency and the management of risk. Food regulatory authorities around the world are now very active in implementing these tools in the food industry. A quality management system does not guarantee food safety unless the hazards are identified and controlled.

Recently, the concept of hurdle technology or combined methods of preservation has gained attention. The microbial stability and safety of most traditional and novel foods is based on a combination of several preservative factors (called hurdles), which microorganisms present in the food are unable to overcome. This is illustrated by the so-called hurdle effect, first introduced by Leistner and his coworkers. He acknowledged that the hurdle concept illustrates only the well-known fact that complex interactions of temperature, water activity, pH, and redox potential are significant for the microbial stability of foods. With respect to procedures that slow down or prevent the growth of microorganisms in foods, major successes have been seen and new applications are steadily being made in the use of *combination preservation techniques* or *hurdle technology*. This has been supported by a greatly improved understanding of the principles underlying the stability and safety of an enormous number of combination-preserved foods that are traditional and indigenous to different parts of the world. Modified-atmosphere packaging has grown rapidly, particularly for the extension of the high-quality shelf life of certain chill-stored foods.

1.6 Other Preservation Factors

Applications of modern biotechnology with genetic modification will play a more important role in the future for more value-added products, and easy and efficient methods of preservation. Biotechnology is a general term for several techniques that use living organisms to make or modify products for a specific purpose. The techniques of biotechnology offer opportunities to address consumer issues of food quality and environmental safety. Biotechnology can be used to make fruits more flavorsome; to improve nutritional and functional quality of fruits, vegetables, grains, and muscle foods; to grow foods in a wider climate zone; and to grow foods in a more environmentally benign fashion [4]. The biggest application of biotechnology will be rapid and sensitive diagnostic kits for the detection of pathogens and unwanted xenobiotic compounds in foods. Another application of biotechnology will be on-package sensors that could indicate when a food is spoiled, or when a pathogen or its toxic by-product is present at some level of concern [13].

The major driving forces in the development and modification of food processing are the desire to reduce the extent of processing, i.e., the demand for *lightly processed* or *fresh-like,* organic, and natural foods; the desire to maximize automation, control, and efficiency; and the desire to minimize cost, and the need to respond to an ever-increasing strict regulations concerning environmental impact of various processes [11]. Nonthermal preservation technology is used to maintain nutrition and quality. There is a tendency to reduce intake of animal products, and to consume more cereal and cereal-based products, fruits, and vegetables. Other technologies being developed to meet the consumer desire for minimally processed foods is the shift from heat treatment for pasteurization and cooking, to use of electromagnetic waves, such as electron-beam and gamma radiation and microwave radiation. Microwave applications are easily accepted by the consumer but have never made major changes at the processing level. One of the major problems of this technology is to permit appropriate textures for the products while using intensities high enough to kill all pathogens despite their rapid time–temperature history [13]. Other potential electromagnetic processing techniques that can be used to minimize adverse heat changes due to cooking include pulsed light at high intensity, pulsed magnetic fields, direct current in a particulate stream (ohmic heating), pulsed electric discharge, and radio frequencies such as infrared. Food processing is very energy-intensive, and reducing energy use by using efficient electrotechnology can increase profit as well as reduce environmental impact. In many cases, fast or rapid heating by electrotechnology may not provide enough time to develop desired textures and flavors.

Food habits have been a very important component of human society since its inception. Changing trends and lifestyles demand more specific attributes. These include convenience in preparation and consumption, changing taste preferences, attitudes and perceptions about diet and health, more nutritional and functional advances in technology that influence food quality and availability, economic factors, ethnic and geographic regional factors, age, and suitability and convenience for lifestyle [4]. Eating away from home no longer means just sitting down in a restaurant. It can be done while sitting in a car, a train, a park bench, or at an office desk. New types of fast foods are emerging to meet the demand, and safety and innovation are needed. Taste, nutrition, and convenience are the driving forces in today's market. There is also a great emphasis on simple meal preparation at home, especially with microwave cooking.

Antinutritional factors in many raw materials need to be considered and adequate pretreatments should be used before major preservation steps. It is important to reduce pesticide residues in the final products and these must be used as little as possible. There is increasing utilization of integrated pest management (IPM) as a part of growing and processing. Usually pesticide residues decrease, often dramatically, during processing and preparation. The process of washing and peeling fruits and vegetables generally results in significant declines in the amount of pesticide detected in the food. This is especially true for pesticide residues that are found only on the surface of the commodity [18]. The amount of residue depends largely on the pesticide, the commodity, and the process used. Exceptions may also occur when processing causes degradation of the chemical, creating a chemical that is more toxic than the parent chemical. A stewardship program is used for control of pesticide residues. There is great consumer concern regarding potentially harmful chemicals in the food supply, such as hydrocarbons, dioxin, and heavy metals.

The factors that should be considered before selecting a preservation process are the desired quality of the products, the economics of the process, and the environmental impact of the methods. Food industry waste is now also of concern to law-enforcing authorities and consumers. Food waste is not only an economic loss, but it also has an impact on the environment. It is important to make every effort to minimize waste, set up effective recycling systems, and implement suitable systems for value-added products. The ultimate success of the food industry lies in the timely adoption and efficient implementation of the emerging new technologies to satisfy the present and the future demands of the consumer.

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