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REVIEW

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A review on mechanisms and commercial aspects of food preservation and processing

Sadat Kamal Amit[†], Md. Mezbah Uddin[†], Rizwanur Rahman, S. M. Rezwanul Islam and Mohidus Samad Khan[*]

Abstract

Food preservation involves different food processing steps to maintain food quality at a desired level so that maximum benefits and nutrition values can be achieved. Food preservation methods include growing, harvesting, processing, packaging, and distribution of foods. The key objectives of food preservation are to overcome inappropriate planning in agriculture, to produce value-added products, and to provide variation in diet. Food spoilage could be caused by a wide range of chemical and biochemical reactions. To impede chemical and microbial deterioration of foods, conventional and primitive techniques of preserving foods like drying, chilling, freezing, and pasteurization have been fostered. In recent years, the techniques to combat these spoilages are becoming sophisticated and have gradually altered to a highly interdisciplinary science. Highly advanced technologies like irradiation, high-pressure technology, and hurdle technology are used to preserve food items. This review article presents and discusses the mechanisms, application conditions, and advantages and disadvantages of different food preservation techniques. This article also presents different food categories and elucidates different physical, chemical, and microbial factors responsible for food spoilage. Furthermore, the market economy of preserved and processed foods has been analyzed in this article.

Keywords: Food category, Food spoilage, Food preservation, Food processing, Global market

Background

Foods are organic substances which are consumed for nutritional purposes. Foods are plant or animal origin and contain moisture, protein, lipid, carbohydrate, minerals, and other organic substances. Foods undergo spoilage due to microbial, chemical, or physical actions. Nutritional values, color, texture, and edibility of foods are susceptible to spoilage [1]. Therefore, foods are required to be preserved to retain their quality for longer period of time. Food preservation is defined as the processes or techniques undertaken in order to maintain internal and external factors which may cause food spoilage. The principal objective of food preservation is to increase its shelf life retaining original nutritional values, color, texture, and flavor.

The history of 'Food Preservation' dates back to ancient civilization when the primitive troupe first felt the necessity for preserving food after hunting a big animal, which could not be able to eat at a time. Knowing the techniques of preserving foods was the first and most important step toward establishing civilization. Different cultures at different times and locations used almost the similar basic techniques to preserve food items [2].

Conventional food preservation techniques like drying, freezing, chilling, pasteurization, and chemical preservation are being used comprehensively throughout the world. Scientific advancements and progresses are contributing to the evolution of existing technologies and innovation of the new ones, such as irradiation, high-pressure technology, and hurdle technology [3–5]. The processing of food preservation has become highly interdisciplinary since it includes stages related to growing,

*Correspondence: mohid@che.buet.ac.bd
[†]Sadat Kamal Amit and Md. Mezbah Uddin contributed equally to this work
Department of Chemical Engineering, Bangladesh University of Engineering and Technology (BUET), Dhaka 1000, Bangladesh

harvesting, processing, packaging, and distribution of foods. Therefore, an integrated approach would be useful to preserve food items during food production and processing stages.

At present, the global market of the processed food items is about 7 trillion dollars, which is gradually growing with time [6]. Rapid globalization and industrialization are the major contributing factors for the progress of food processing industries in different countries. An analysis of the UNIDO Industrial Statistics Database (2005) shows that food processing in developing countries is an auspicious component of the manufacturing sector, and the contribution of food processing industries to the national GDP increases with country's national income [7, 8].

This review paper presents the classification of food items and discusses different physical, chemical, and biological factors of food spoilage. The basics and advancements of different trivial and modern food preservation techniques, which are attributed to impede food spoilage and to yield longer shelf life, are discussed here along with their mechanisms, application conditions, advantages, and disadvantages. This article also reports the global market trend of preserved and processed food. Figure 1 summarizes a flow diagram showing various categories of foods, components of food spoilage mechanisms, food preserving and processing methods, and global market analysis of preserved foods. This review offers the researchers, technologists, and industry managements a comprehensive understanding that could be highly useful to develop effective and integrated food preservative methods and to ensure food safety.

Classification of foods

Foods can be broadly classified according to the shelf life, functions and nutrient value, and processing mechanisms (Fig. 2). Different categories of foods are summarized in Table 1 and briefly discussed in the following sections.

Food categories based on shelf life

Food spoilage is a natural process; through this process, food gradually loses its color, texture, flavor, nutritional qualities, and edibility. Consumption of spoiled food can lead to illness and in the extreme situation to death [9]. Considering the self life, food items can be classified as perishable, semi-perishable, and non-perishable [10].

Perishable Foods that have shelf life ranging from several days to about three weeks are known as perishable. Milk and dairy products, meats, poultry, eggs, and seafood are the examples of perishable food items. If special

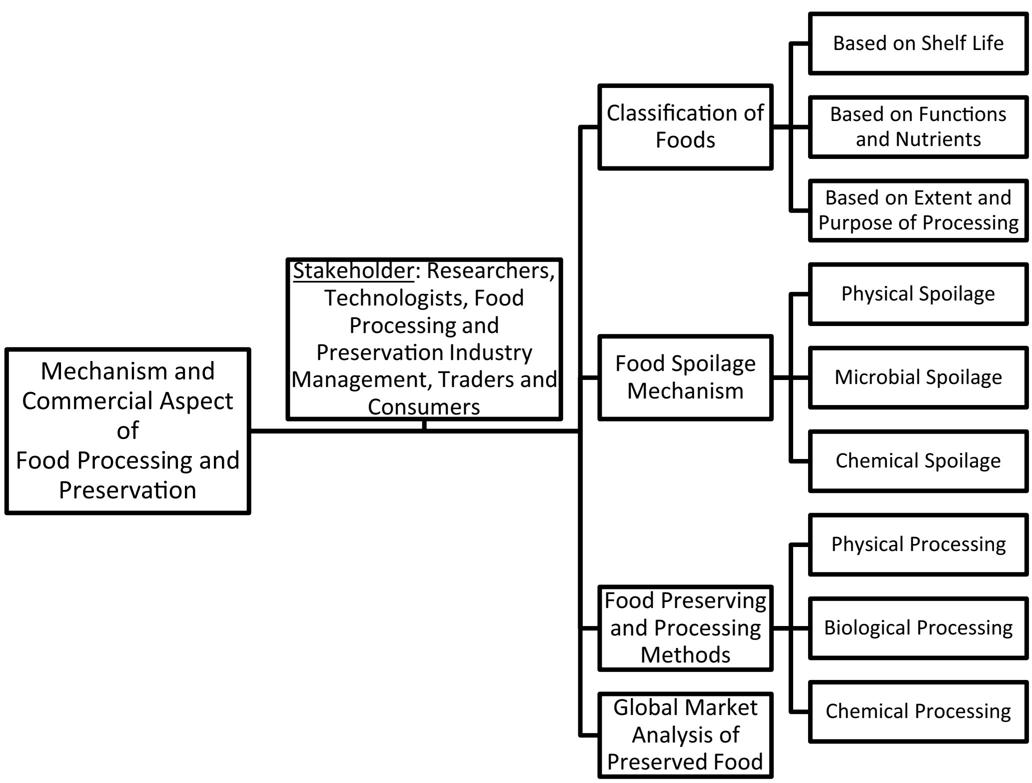

Fig. 1 Summary of the review on mechanisms and commercial aspects of food preservation and processing

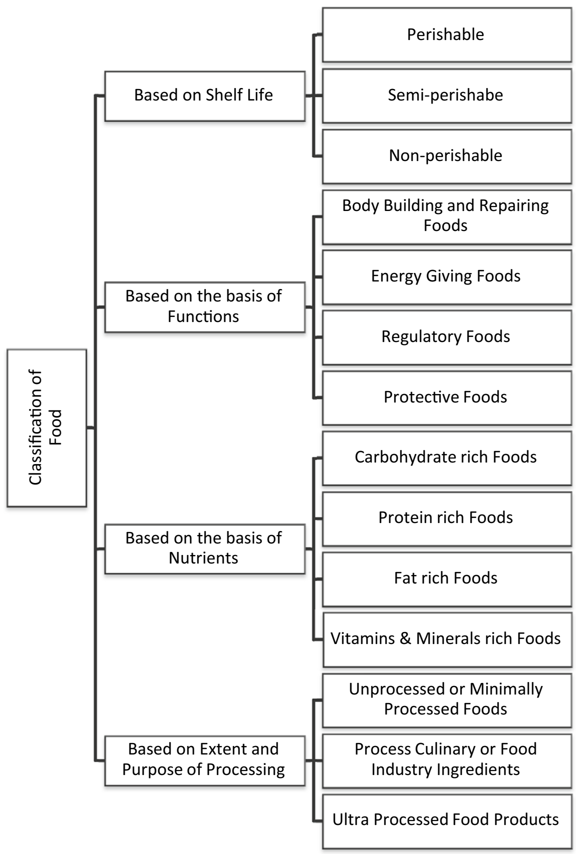

Fig. 2 Classification of food, recreated from references [9–12]

preservation techniques are not apprehended, food items could be spoiled straight away [10].

Semi-perishable Different food items can be preserved for long time (about six months) under proper storage conditions. These foods are known as semi-perishable. Vegetables, fruits, cheeses, and potatoes are few examples of semi-perishable food items.

Non-perishable Natural and processed foods that have indefinite shelf life are called non-perishable food items. These foods can be stored for several years or longer. Dry beans, nuts, flour, sugar, canned fruits, mayonnaise, and peanut butter are few examples of non-perishable foods.

Food categories based on functions and nutrients

According to the functions to human body, food items can be categorized as: (a) body building and repairing foods, (b) energy-giving foods, (c) regulatory foods, and (d) protective foods. Depending on the nutrition value, food items can be classified as: (a) carbohydrate-rich foods, (b) protein-rich foods, (c) fat-rich foods, and (d) vitamin- and mineral-rich foods. Table 1 presents different food items according to their functions and nutrients.

Table 1 Classification of foods based on functions and nutrients [13]

	Sources
Functions	
Body building and repairing foods	Milk, meat, fish, pulses, vegetables, and nuts
Energy-giving foods	Oil, butter, sugar, cereals, dry fruits, and starch foods
Regulatory foods	Water, raw vegetables, citrus fruits, and beverages
Protective foods	Milk, whole grain cereals, meat, vegetables, and fruits
Nutrients	
Carbohydrate-rich foods	Rice, wheat, and starchy vegetables
Protein-rich foods	Milk, meat, fish, egg, and nuts
Fat-rich foods	Oils, butter, and egg yolk
Vitamin- and mineral-rich foods	Fruits and vegetables

Food categories based on extent and purpose of processing

Different food processing techniques are used by the food industries to turn fresh foods into food products. Foods can be classified into three major groups based on the extent and purpose of food processing [14]: (a) unprocessed or minimally processed foods, (b) processed culinary or food industry ingredients, and (c) ultra-processed food products. Classification of foods based on extent and purpose of processing is presented in Table 2.

Food spoilage: mechanism

Food spoilage is the process in which food edibility reduces. Food spoilage is related to food safety [9]. The primitive stage of food spoilage can be detected by color, smell, flavor, texture, or food. Different physical, microbial, or chemical actions can cause food spoilage. These mechanisms are not necessarily mutually exclusive since spoilage caused by one mechanism can stimulate another. Temperature, pH, air, nutrients, and presence of different chemicals are the major factors for food spoilage [9]. Different factors that affect food spoilage are presented in Fig. 3 and briefly discussed in the following sections.

Physical spoilage

Food spoilage due to physical changes or instability is defined as physical spoilage. Moisture loss or gain, moisture migration between different components, and physical separation of components or ingredients are the examples of physical spoilage [9, 15–24]. The key factors affecting physical spoilage are moisture content, temperature, glass transient temperature, crystal growth, and crystallization.

Table 2 Food classification based on the extent and purpose of processing [14]

Food group	Extent and purpose of processing	Examples
Unprocessed or minimally processed foods	No processing or mostly physical processes used to make single whole foods more available, accessible, palatable, or safe	Fresh, chilled, frozen, vacuum-packed fruits, vegetables, cereals; fresh frozen and dried beans and other pulses; dried fruits, unsalted nuts, and seeds; fresh, dried, chilled, frozen meats, poultry, and fish; fresh and pasteurized milk, yoghurt, eggs, tea, and coffee
Processed culinary or food industry ingredients	Extraction and purification of components of foods, resulting in producing ingredients used in the preparation and cooking of dishes and meals, or in the formulation of ultra-processed foods	Vegetables, butter, milk cream, sweeteners, raw pastas, and noodles; food industry ingredients, such as high-fructose corn syrup, preservatives, and cosmetic additives
Ultra-processed food products	Processing of a mix of process culinary, or food industry ingredients and processed or minimally processed foodstuffs in order to produce accessible, convenient, palatable, ready-to-eat or to-heat food products with longer shelf life	Breads, biscuits, cakes, and pastries; ice-cream, chocolates, cereal bars, chips; sugared fruits, milk drinks, and other soft drinks; pre-prepared meat, poultry, fish, and vegetable; processed meat including chicken nuggets, hot dogs, sausages, burgers; salted, pickled, smoked, or cured meat and fish; vegetables bottled or canned in brine; fish canned in oil

Moisture content

A frequent cause of degradation of food products is the change in their water content. It may occur in the form of water loss, water gain, or migration of water [25]. Moisture transfer in food is directly related to the water activity (a_w) of food item [9, 26]. Water activity (a_w) is a thermodynamic property which is expressed as the ratio of the vapor pressure of water in a system to the vapor pressure of pure water at the same temperature [15, 27]. Equilibrium relative humidity at the same temperature may also be used in lieu of pure water vapor pressure. Water activity in food products reduces with temperature. In general, water activity of foods at normal temperature is 1.0, whereas at −20 and −40 °C temperatures the water activities are 0.82 and 0.68, respectively [16, 17, 21].

Temperature

The effect of temperature is the most significant factor in the case of fruit and vegetable spoilage. There is an optimum temperature range for slow ripening and to maximize post-harvest life. Slow ripening also requires an optimum relative humidity along with optimum air movement around fruit and vegetable. Apparently, these optimum conditions are called modified atmospheres (MA). Temperature usually besets the metabolism of the commodities and contemporarily alters the rate of attaining desired MA [17]. Low temperature can also have a negative effect on foods that are susceptible to freeze damage. At a lower temperature, when food products become partially frozen, breakage in cells occurs which damages the product. Most tropical fruits and vegetables are sensitive to chilling injury. This generally occurs before the food product starts to freeze at a temperature in between 5 °C and 15 °C [9].

Glass transition temperature

Glass transition temperature (T_g) effects the shelf life of food products. Solids in food items may exist in a crystalline state or in an amorphous metastable state. This phenomenon depends on the composition of solids, temperature, and relative humidity [18]. The amorphous matrix may exist either as a very viscous glass or as a more liquid-like rubber [19]. At glass transition temperature, changes occur from the glassy state to rubbery state. This is a second-order phase transition process, which is temperature specific for each food. The physical stability of foods is related to the glass transition temperature. Glass transition temperature (T_g) depends strongly on concentration of water and other plasticizers [22]. When dry food products are kept in highly humid conditions, the state of food products changes due to glass transition phenomena [9].

Crystal growth and crystallization

Freezing can also contribute to food degradation. Foods, which undergo slow freezing or multiple freeze, suffer severely due to crystal growth. They are subject to large extracellular ice growth. Rapid freezing forms ice within food cells, and these foods are more stable than slow freezing processed foods [23]. To minimize large ice crystal growth, emulsifiers and other water binding agents can be added during freezing cycles [20].

Foods with high sugar content can undergo sugar crystallization either by moisture accumulation or by increasing temperature. As a consequence, sugar comes to the surface from inside, and a gray or white appearance is noticed. Staling of sugar cookies, graininess in candies, and ice creams are the results of sugar crystallization [9]. Sugar crystallization can be delayed by the addition of fructose or starch. Moreover, above the respective glass

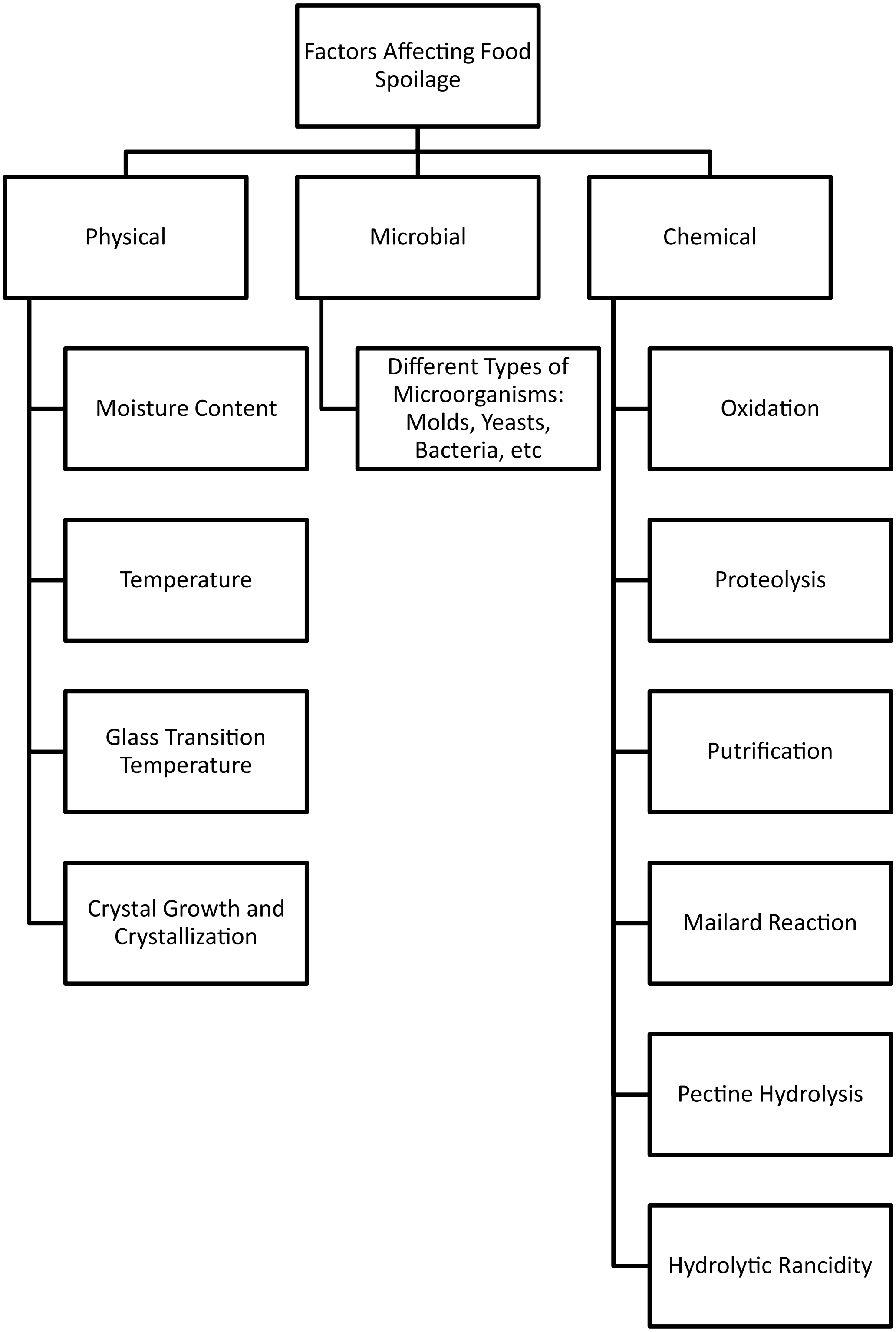

Fig. 3 Key physical, microbial, and chemical factors affecting food spoilage [9]

transition temperature, time plays a crucial role in sugar crystallization process of food items [24].

Microbial spoilage

Microbial spoilage is a common source of food spoilage, which occurs due to the action of microorganisms. It is also the most common cause of foodborne diseases. Perishable foods are often attacked by different microorganisms. The growth of most microorganisms can be prevented or lingered by adjusting storage temperature, reducing water activity, lowering pH, using preservatives, and using proper packaging [28].

Microorganisms involved in food spoilage

Microorganisms involved in food spoilage can be divided into three major categories, which are molds, yeasts, and bacteria. Table 3 presents the active conditions of different microorganisms that affect foods.

Factors affecting microbial spoilage

There are intrinsic and extrinsic factors that can affect microbial spoilage in foods [29]. The intrinsic properties of foods determine the expected shelf life or perishability of foods and also affect the type and rate of microbial spoilage. Endogenous enzymes, substrates, sensitivity of light, and oxygen are the primary intrinsic properties associated with food spoilage [33]. To control food quality and safety, these properties can be controlled during food product formulation [10]. Intrinsic factors of food spoilage include pH, water activity, nutrient content, and oxidation–reduction potential [9, 10, 29]. Extrinsic factors of food spoilage include relative humidity, temperature, presence, and activities of other microbes [9, 29].

Chemical spoilage

Chemical and biochemical reactions occur naturally in foods and lead to unpleasant sensory results in food products. Fresh foods may undergo elementary quality changes caused by: (a) microbial growth and metabolism which results in pH changes, (b) toxic compounds, and/or (c) the oxidation of lipids and pigments in fat which results in undesirable flavors and discoloration [33, 34]. Chemical spoilage is interrelated with microbial actions. However, oxidation phenomena are purely chemical in nature and also dependent on temperature variations [33].

Oxidation

In presence of oxygen, amino acids convert into organic acid and ammonia. This is the elementary spoilage reaction in refrigerated fresh meat and fish [29].

$$\text{Amino acid} + O_2 \xrightarrow{\text{deaminase}} NH_3 + \text{Organic acid}$$

The term 'rancidification' is used to denominate lipids oxidation through which unsaturated fats (lipids) undergo reaction with oxygen [35]. The consequences in food items are color alteration, off-flavor, and toxic substances formation [9]. Rancidification can be catalyzed by the presence of metal oxides and exposure to light increases the reaction rate. After this reaction, carbonyl compounds, responsible for rancid taste of foods, are produced [35]. Figure 4 presents auto-oxidation of fatty acids (RH).

Proteolysis

Proteolysis, a ubiquitous and irreversible posttranslational modification, involves limited and highly specific hydrolysis of peptide and iso-peptide bonds of a protein. The entire phenomena require the presence of miscellaneous protease enzymes [36]. Different specialized proteases play a key role in various regulatory processes. Moreover, highly specific proteolytic events are associated with normal and pathological conditions [37]. Foods containing nitrogen compounds frequently incur this reaction. Proteins, after being incurred through proteolysis, eventually get converted into small-sized amino acids. The following reaction presents proteolysis mechanism:

Table 3 Active conditions of different microorganisms and affected foods [10, 29–32]

Microorganisms	Active condition				Affected foods
	pH	Temperature	Water activity	Heat sensitivity	
Molds	3.0–8.0	Grow across a wide range of temperature	0.62–1.0	Heat sensitive	Bottled mineral water, fermented foods
Yeasts	Grow around a broad range of acidic pH	Grow across a wide range of temperature, but prefer natural ambient temperature	Above 0.9	Heat resistant and can survive under scorching sunlight	Fermented foods
Bacteria	Broad pH range	Prefer growth at high temperature (≥55 °C)	Above 0.9 for gram positive and above 0.98 for gram negative	Mostly thermophiles	Fresh meat, poultry, sea food, eggs, and heat-treated foods

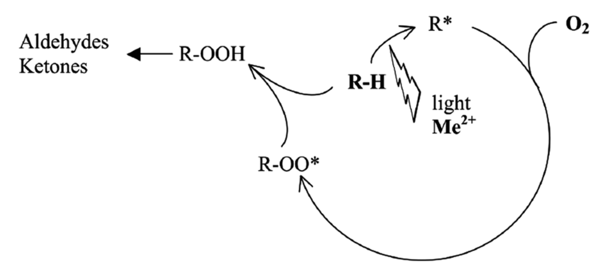

Fig. 4 Auto-oxidation of fatty acids (RH) [35]

$$\text{Proteins} \xrightarrow{\text{proteinase}} \text{Peptides} \xrightarrow{\text{peptidase}} \text{Amino Acids.}$$

Many of these peptides have stiff taste which can be bitter or sweet [35]. Table 4 presents the taste of various amino acids [38].

Putrefaction

Putrefaction refers to the series of anaerobic reactions through which amino acids detour to a mixture of amines, organic acids, and stiff-smelling sulfur compounds, such as mercaptans and hydrogen sulfide. This is a biochemical phenomenon as the presence of bacteria is exigent all through the process. Along with amino acids, indole, phenols, and ammonia are also formed due to protein putrefaction [39]. Most of these chemicals have displeasing odor. Putrefaction is quite common in meats and other protein-rich foods at temperatures greater than 15 °C. This elevated temperature facilitates microbial activities [35, 39].

Maillard reaction

Non-enzymatic browning, which is also known also as Maillard reaction, is another primary cause of food spoilage. This reaction occurs in the amino group of proteins, or the amino acids present in foods. Color darkening, reducing proteins solubility, developing bitter flavors, and reducing nutritional availability of certain amino acids are the common outcomes of Maillard reaction. This reaction occurs during the storing of dry milk, dry whole eggs, and breakfast cereals [40].

Table 4 Taste of different amino acids

Taste	Amino acids
No taste/barely perceptible taste	D-Alanine, D-arginine, L-arginine, D-aspartate, L-aspartate, D-glutamate, L-histidine, D-isoleucine, L-isoleucine, D-lysine, L-lysine, D-proline, L-proline, D-serine, L-serine, L-threonine, D-valine, L-valine
Sweet taste	D-Tryptophan, D-histidine, D-phenylalanine, D-tyrosine, D-leucine, L-alanine, glycine
Bitter taste	L-Tryptophan, L-phenylalanine, L-tyrosine, L-leucine
Sulfurous taste	D-Cysteine, L-cysteine, D-methionine, L-methionine
Unique taste	L-Glutamic acid

Pectin hydrolysis

Pectins are complex mixtures of polysaccharides that make up almost one-third of the cell wall of dicotyledonous and some monocotyledonous plants [41, 42]. Indigenous pectinases are synthesized or activated during ripening of fruits and cause pectin hydrolysis which softens the structure of food. Damages of fruits and vegetables by mechanical means may also activate pectinases and initiate microbial attack [35]. Pectin substances may also be de-esterified by the action of pectin methyl esterase. This esterification process is initiated in situ on damaged tissues, firm fruits, and vegetables by strengthening the cell walls and enhancing intercellular cohesion via a mechanism involving calcium. Metal ions catalyze the decomposition of heat-labile fruit pigments, which consist of pectin ingredients. This process causes the color change in fruit jams or jellies [42]. Therefore, jams and jellies are preserved in glass containers rather than metallic jars.

Hydrolytic rancidity

Hydrolytic rancidity causes lipid degradation by the action of lipolytic enzymes. In this reaction, free fatty acids are cleaved off triglyceride molecules in the presence of water. These free fatty acids have rancid flavors or odor [9]. The released volatile fatty acids have a stiff malodor and taste; therefore, hydrolytic rancidity is extremely noticeable in fats, such as butter [43].

Food preserving and processing methods

Food preservation refers to the process or technique undertaken in order to avoid spoilage and to increase shelf life of food [44, 45]. Different preservation and processing techniques are presented in Fig. 5 [46–48].

Physical processing

Drying

Drying or dehydration is the process of removing water from a solid or liquid food by means of evaporation. The purpose of drying is to obtain a solid product with sufficiently low water content. It is one of the oldest methods of food preservation [49]. Water is the prerequisite for the microorganisms and enzymes to activate food spoilage mechanisms. In this method, the moisture content is lowered to the point where the activities of these microorganisms are inhibited [29, 50]. Most microorganisms can grow at water activity above 0.95. Bacteria are inactive at water activity below 0.9. Most of the microorganisms cannot grow at water activity below 0.88 [51, 52].

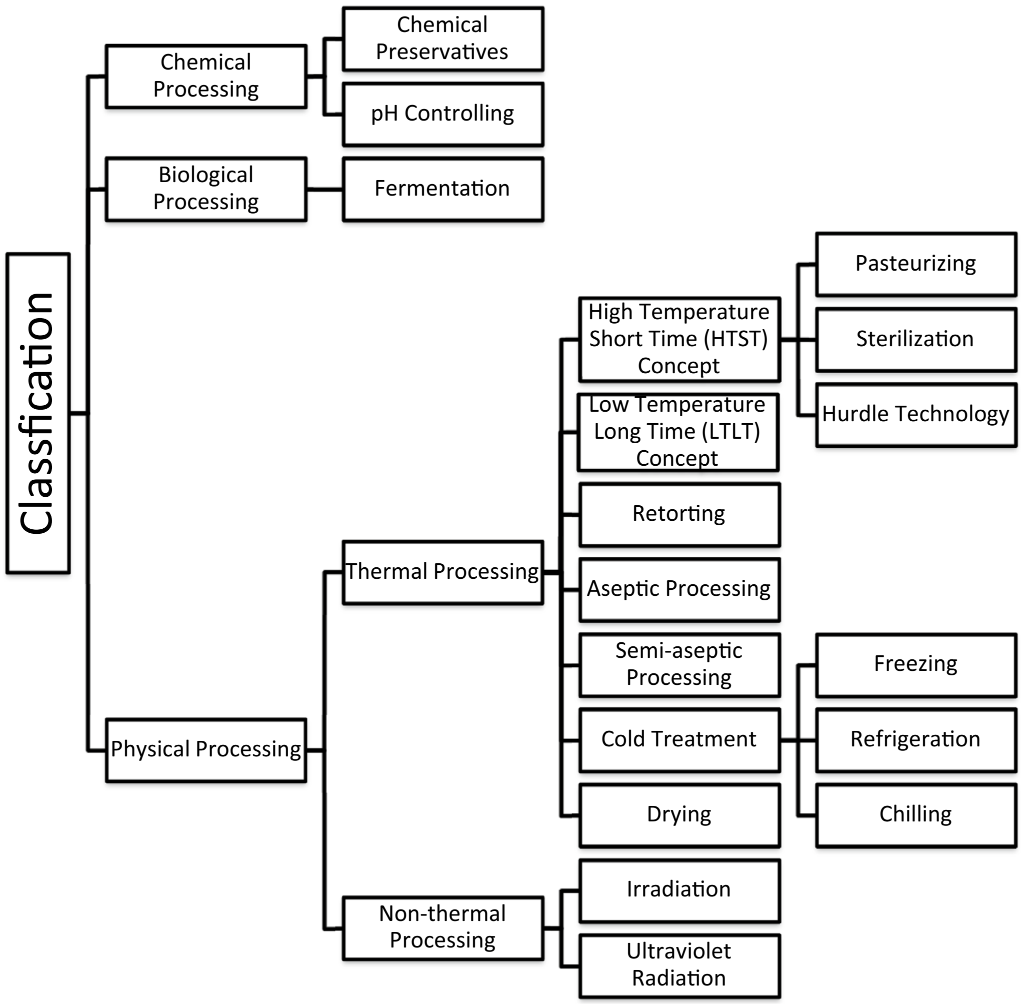

Fig. 5 Classification of food preservation and processing methods, recreated from references [46–48]

Drying has numerous advantages. It reduces weight and volume of foods, facilitates foods storage, packaging, and transportation, and also provides different flavors and smells. With all these benefits, drying is apparently the cheapest method of food preservation [53]. However, this process also has limitations. In some cases, significant loss of flavor and aroma has been observed after drying. Some functional compounds like vitamin C, thiamin, protein, and lipid are also lost because of drying [54–56].

Classification of drying Drying can be classified into three major groups: convective, conductive, and radiative. Convective drying is the most popular method to obtain over 90% dehydrated foods. Depending on the mode of operation, dryers can be classified as batch or continuous. For smaller-scale operations and short residence times, batch dryers are preferred. Continuous method of drying is preferential when long periodic operations are required and drying cost is needed to curtail [57].

Drying of different foods Food items, such as fruits, vegetables, meats, and fishes, are processed by drying. Instant coffee and tea are also produced by spray drying or freeze drying [58, 59]. Processing temperature and drying time of different food items are presented in Table 5.

Pasteurization Pasteurization is a physical preservation technique in which food is heated up to a specific temperature to destroy spoilage-causing microorganisms and enzymes [64, 65]. Almost all the pathogenic bacteria, yeasts, and molds are destroyed by this process. As a result, the shelf life of food increases [66, 67]. This process was named after the French scientist Louis Pasteur (1822–1895), who experimented with this process in 1862. He used this process to treat wine and beer [68].

Table 5 Processing temperature and time for different food products [59–63]

Foods to be dried	Processing temperature and time
Fruits	
Cherries	70 °C for 2–3 h; 55 °C until dry
Coconuts	45 °C until dry
Pineapples	70 °C for 1–2 h; 55 °C until dry
Persimmons	60 °C for 1–2 h; 55 °C until dry
Pears (Asian)	60 °C
Vegetables	
Asparagus	60 °C for 2–3 h; 55 °C until dry
Beans, green	60 °C for 2 h; 55 °C until dry
Mushrooms	25–30 °C for 2–3 h; increase to 50 °C until dry
Onions	70 °C for 1–2 h; 55 °C until dry
Parsley	30 °C to 50 °C; may be room dried
Fish	
Carp	4 °C under high pressure for 15–20 min
Prawn	70 °C for 30 min
Meat	
All	80 °C for 2 h

Table 6 presents the applications of pasteurization process to preserve different food items.

Pasteurization techniques The efficiency of pasteurization depends on the temperature–time combination. This combination is mostly based on the thermal death-time studies of heat-resisting microorganisms [55]. On the basis of temperature and heat exposure, pasteurization can be categorized as vat (batch), high temperature short time (HTST), and ultra-high temperature (UHT); HTST and UHT are continuous processes [16, 69]. Vat pasteurizer is suitable for small plants having the capacity of 100–500 gallons [56]. Vat pasteurization requires constant supervision to prevent overheating, over holding, or burning [44]. High-temperature short-time (HTST) pasteurization is a continuous process pasteurizer equipped with sophisticated control system, pump, flow diversion devices or valves, and heat exchanger equipment [56]. HTST pasteurization is also known as 'flash pasteurization' [56, 70]. Vat and HTST pasteurization perishes pathogenic microorganisms effectively. However, to inactivate thermo-resisting spores ultra-high temperature (UHT) pasteurization is more effective than VAT and HTST [55]. During heat treatment of food items, minimal physical, chemical, or biological changes take place [71]. After heating is done, the products are aseptically packaged in sterile containers [46]. UHT pasteurized products have a longer shelf life than other pasteurized products. Table 7 presents the comparisons between the three pasteurization methods.

High heat of pasteurization process may damage some vitamins, minerals, and beneficial bacteria during pasteurization. At pasteurization temperature, Vitamin C is reduced by 20 per cent, soluble calcium and phosphorus are reduced by 5 per cent, and thiamin and vitamin B12 are reduced by 10 per cent. In fruit juices, pasteurization causes reduction in vitamin C, ascorbic acid, and carotene. However, these losses can be considered minor from nutritional point of view [44, 72].

Thermal sterilization

Thermal sterilization is a heat treatment process that completely destroys all the viable microorganisms (yeasts, molds, vegetative bacteria, and spore formers) resulting in a longer period of shelf life [44]. Retorting and aseptic processing are two categories of thermal sterilization [44, 73]. Thermal sterilization is different from pasteurization. Comparison of different criteria between pasteurization and sterilization is given in Table 8.

Retorting

Retorting is defined as the packaging of food in a container followed by sterilization [73]. Foods with pH above 4.5 require more than 100 °C as sterilization temperature. The attainment of such temperature can be possible in

Table 6 Pasteurization of different foods [44]

Food type	Main purpose	Sub-purpose	Typical temperature–time combination used
Fruit juice (pH < 4.5)	Inactivation of enzymes (pectinesterase, polygalacturonase)	Destruction of spoilage-causing microorganisms (*Salmonella enterica, Cryptosporidium parvum*)	65 °C for 30 min, 77 °C for 1 min, or 88 °C for 15 s
Beer (pH < 4.5)	Destruction of spoilage-causing microorganisms (wild yeasts, *Lactobacillus* species)	Destruction of spoilage-causing microorganisms	65 to 68 °C for 20 min (in bottle) or 72–74 °C for 1–4 min at 900–1000 kPa
Milk (pH > 4.5)	Destruction of pathogens (*Brucellaabortis, Mycobacterium tuberculosis*)	Destruction of spoilage-causing microorganisms (*Streptococcus laptis, Streptococcus cremoris*) and enzymes	63 °C for 30 min or 71.5 °C for 15 s
Liquid egg	Destruction of pathogens (*Salmonella seftenburg*)	Destruction of spoilage-causing microorganisms	64.4 °C for 2.5 min or 60 °C for 3.5 min

Table 7 Comparison between different pasteurization techniques [44, 55, 69]

Criteria	VAT	HTST	UHT
Process type	Batch	Continuous	Continuous
Typical temperature–time combination	65 °C for 30 min	72 °C for 15–30 s	135–150 °C for a few seconds
Foods preserved	Butter milk and sour cream	Milk, eggnog, frozen dessert mixes, fruit juices, etc.	Milk
Shelf life increase (milk)	Several days when refrigerated	2–3 weeks when refrigerated	6–9 months when aseptically packaged
Type of microbes destroyed	Vegetative pathogens	Vegetative pathogens	All bacteria and spores

Table 8 Comparison between pasteurization and sterilization [74, 75]

Criteria	Pasteurization	Sterilization
Temperature level	Mild heat treatment process. Temperature level 65–75 °C (exception: UHT)	Severe heat treatment process. 135–140 °C and up to 150 °C are applied
Status of heat-resisting microorganisms	Many heat-resisting microorganisms, viruses, and spores may remain alive	Bacteria species, spores, and thermophiles
Change in nutritional capacity and profile	Negligible	Fats, protein, and sugar may decompose; calcium, minerals, and vitamins may escape
Storage	Refrigerated conditions	Ambient temperature
Product parameter (pH)	3.5 < pH < 4.6	pH > 4.6
Shelf life extension	For few days to weeks	For months

batch or continuous retorts. Batch retorts are gradually being superseded by continuous systems [75]. Hydrostatic retorts and rotary cookers are the most common continuous systems used in food industries [76]. Table 9 presents different criteria of batch and continuous retorts.

Aseptic packaging

Aseptic packaging involves placing commercially sterilized food in a sterilized package which is then subsequently sealed in an aseptic environment [79]. Conventional aseptic packaging utilizes paper and plastic materials. Sterilization can be achieved either by heat treatment, by chemical treatment, or by attributing both of them [79]. Aseptic packaging is highly used to preserve juices, dairy products, tomato paste, and fruit slices [75]. It can increase the shelf life of food items to a large extent; as an example, UHT pasteurization process can extend the shelf life of liquid milk from 19 to 90 days, whereas combined UHT processing and aseptic packaging extend shelf life to six months or more. Packages used for aseptic processing are produced from plastics having relative softening temperature. Moreover, aseptic filling can accept a wide range of packaging materials including: (a) metal cans sterilized by superheated steam, (b) paper, foil, and plastic laminates sterilized by hot hydrogen peroxide, and (c) a variety of plastic and metal containers sterilized by high-pressure steam [80]. Wide variation of packages thus enhances proficiency of aseptic packaging and diminishes cost.

Table 9 Comparison between batch and continuous retorts [75, 77, 78]

Criteria	Batch retort	Continuous retort
Capital investment	Low capital investment and higher flexibility	Initial investment is high
Throughputs	Lower	Higher
Energy	Energy and labor intensive	Provides scope for energy saving
Time of heating to sterilization temperature	2–6 h	0.5–3 min
Sterilization time	20–60 min	15–90 s
Cooling time after sterilization	4–10 h	5–10 min
Food items	Useful in food processing operations which produce a mix of products in a number of package sizes	Baby foods in jar, pet foods, soup, canned meat, and beverages; acidic foods such as tomato products

The direct approach of aseptic packaging comprises of steam injunction and steam infusion. On the other hand, indirect approach of aseptic packaging includes exchanging heat through plate heat exchanger, scrapped surface heat exchanger, and tubular heat exchanger [81]. Steam injection is one of the fastest methods of heating and often removes volatile substances from some food products. On the contrary, steam infusion offers higher control over processing conditions than steam injection and minimizes the risk of overheating products. Steam infusion is suitable to treat viscous foods [81]. Tubular heat exchangers are adopted for operations at higher pressures and flow rates. These exchangers are not very flexible to withstand production capacity alteration, and their use is only limited to low viscous foods. Plate exchangers, on the other hand, overcome these problems. However, frequent cleaning and sterilizing requirements have made this exchanger less popular in food industries [81].

Freezing

Freezing slows down the physiochemical and biochemical reactions by forming ice from water below freezing temperature and thus inhibits the growth of deteriorative and pathogenic microorganisms in foods [82, 83]. It reduces the amount of liquid water in the food items and diminishes water activity [84]. Heat transfer during freezing of a food item involves a complex situation of simultaneous phase transition and alteration of thermal properties [85]. Nucleation and growth are two basic sequential processes of freezing. Nucleation means the formation of ice crystal, which is followed by 'growth' process that indicates the subsequent increase in crystal size [58].

Freezing time Freezing time is defined as the time required to lower the initial temperature of a product to a given temperature at its thermal center. In general, slow freezing of food tissues results in the formation of larger ice crystals in the extracellular spaces, while rapid freezing produces small ice crystals distributed throughout the tissue [85]. The International Institute of Refrigeration (1986) defines various factors of freezing time in relation to the food products and freezing equipment. Dimensions and shapes of the product, initial and final temperature, temperature of refrigerating medium, surface heat transfer coefficient of the product, and change in enthalpy and thermal conductivity of the product are the most important factors among them [16].

Individual quick freezing Individual quick freezing (IQF) generally relates to quick freezing of solid foods like green peas, cut beans, cauliflower pieces, shrimps, meat chunks, and fish. On the other hand, freezing related to liquid, pulpy or semiliquid products, like fruit juices, mango pulps, and papaya pulps is known as quick freezing. The ice crystals formed by quick freezing are much smaller and therefore cause less damage to cell structure or texture of the food. Shorter freezing period impedes the diffusion of salts and prevents decomposition of foods during freezing. IQF also allows higher capacity for commercial freezing plants with the resultant cost reduction. However, higher investment is required to set up a quick freezing plant [86]. Different quick freezing techniques, such as contact plate freezing, air-blast freezing, and cryogenic freezing, are used to process food items. The comparison between different quick freezing techniques for fishery products is presented in Table 10.

Chilling

In chilling process, the temperature of foods is maintained between −1 and 8 °C. Chilling process reduces the initial temperature of the products and maintains the final temperature of products for a prolonged period of time [88]. It is used to reduce the rate of biochemical and microbiological changes and also to extend shelf life of fresh and processed foods [89]. In practice, freezing process is often referred to chilling, when cooling is conducted at <15 °C [90]. Partial freezing is applied to extend the shelf life of fresh food items in modern food industries. This process reduces ice formation in foods, known as super chilling [91].

Chilling can be done by using various equipments, such as continuous air cooler, ice bank cooler, plate heat exchanger, jacketed heat exchanger, ice implementation system, vacuum attribution system, and cryogenic chamber [92]. Chilling rate is mainly dependent on thermal conductivity, initial temperature of foods, density, moisture content, presence or absence of a lid on the food storage vessel, presence of plastic bags as food packaging equipment, and the size as well as weight of food units [93]. Table 11 describes various methods for chilling solid and liquid food items.

Advantages and disadvantages of chilling Chilling storage is extensively used for its effective short-term preservation competency. Chilling retards the growth of microorganisms and prevents post-harvest metabolic activities of intact plant tissues and post-slaughter metabolic activities of animal tissues. It also impedes deteriorative chemical reactions, which include enzyme-catalyzed oxidative browning, oxidation of lipids, and chemical changes associated with color degradation. It also slows down autolysis of fish, causes loss of nutritive value of foods, and finally bares moisture loss [90]. Chilling is high capital intensive since this process requires specialized equipment and structural modifications. Chilling may reduce crispiness of selected food items [95]. Chilling process also dehydrates unwrapped food

Table 10 Different quick freezing techniques (fishery products) [87]

Criteria	Contact plate freezing	Air-blast freezing	Cryogenic freezing
Capital cost	Low capital investment	Economic to construct and operate	High capital costs
Operating cost	Low operating cost	Higher operating cost	Higher operating cost
Heat transfer	Controlled heat transfer	Efficient heat transfer	Efficient heat transfer
Product line	Generally bulk freezing	Flexible	Flexible
Required floor space	Large	Large	Small
Refrigeration plant	Required	Required	Not required
Maintenance cost	Low	Low	Minimum
Dehydration loss	High	High	Minimum
Product quality	Reasonably good product quality	Good product quality	Superior product quality

Table 11 Chilling methods of solid and liquid foods [94]

Solid foods	Batch air chillers	Warm food items are fed into large refrigerated room, widely used in industry
	Moving air	This cost-effective, hygienic, and widely used method incurs little damage to equipment. Surface dehydration of the food is the major disadvantage of this process
	Ice/ice water chilling	Food items are packed in boxes and then they are placed between layers of crushed ice. Melting ice assists to maintain the temperature at 0 °C. However, this method is not labor efficient and consumes much time comparing to other processes
	Cryogenic cooling	This method involves the use of liquid nitrogen to freeze the product. Thermal shock confrontation of food items makes this process vulnerable
	Immersion cooling/hydrocooling	A cost-effective cooling method is suitable for small products. This technique involves immersing or spraying the product in cool water at near 0 °C. Hydrocooling moisturizes food items which can be detrimental to some extents
Liquid Foods	Batch cooling of liquids	A jacketed stainless steel vessel of varying capacity with agitator inside is usually used for this type of chilling. The coolant may circulate through the jacket of the vessel or through a coil placed in the liquid food stuff, or both while the agitator incurs uniform heat transfer
	Continuous cooling of liquids	The continuous cooling of liquids can involve multi-plates and tubes, aeration, and double-pipe coolers. The most widespread piece of equipment is the multi-plate cooler, which has the best efficiency, high surface area for exchanging heat, easy cleaning opportunity, and less material requirement than others

surfaces, which is a major limitation of chilling process [96].

Irradiation

Irradiation is a physical process in which substance undergoes a definite dose of ionizing radiation (IR) [97]. IR can be natural and artificial. Natural IR generally includes X-rays, gamma rays, and high-energy ultraviolet (UV) radiation; artificially generated IR is accelerated electrons and induced secondary radiation [98, 99]. IR is used in 40 different countries on more than 60 different foods [97]. The effects of IR include: (a) disinfestation of grains, fruits, and vegetables, (b) improvement in the shelf life of fruits and vegetables by inhibiting sprouting or by altering their rate of maturation and senescence, and (c) improvement in shelf life of foods by the inactivation of spoilage organisms and improvement in the safety of foods by inactivating foodborne pathogens [100, 101]. Different factors of food irradiation techniques are listed in Table 12.

Regulatory limits of irradiation The IR dose delivered to foods is measured in kilo grays (kGy). 1 gray is equivalent to ionizing energy dose absorbed by 1 kg of irradiated material. IR regulatory limits are set by the legislative bodies. Depending on the regulatory authority, these limits may be expressed as minimum dose, maximum dose, or approved dose range [98]. Table 13 presents different regulatory limits for food irradiation applications.

Effects of Irradiation The nutritional parameters, such as lipids, carbohydrates, proteins, minerals, and most vitamins, remain unaffected by IR even at high doses [102]. At a high dose, IR may cause the loss of some micronutrients, most notably vitamins A, B1, C, and E. According to FDA, IR has effects on food nutritive value that is similar to those of conventional food processing techniques [102].

High-pressure food preservation

High hydrostatic pressure or ultra-high pressure processing (HPP) technology involves pressure attribution up to

Table 12 Food irradiation technologies [98]

Factors	Electron beam	X-Ray	Gamma ray
Source	Accelerated electrons, typically 5–10 MeV	Induced by impingement of electron beam onto a metal plate. Conversion efficiency is 5–10%	Radioactive decay of Co-60 (2.5 MeV) or Cs-137 (0.51 MeV)
Processing time	Seconds	Seconds	Minutes
Penetration	6–8 cm, suitable for relatively thin or low-density products	30–40 cm, suitable for all products	30–40 cm, suitable for all products
Shielding for operator	>2 m concrete or 0.7 m steel/iron/lead	>2 m concrete or ~0.7 m steel/iron/lead	>5 m water or > 2 m concrete or 0.7 m steel/iron/lead

Table 13 Regulatory limits for food irradiation applications [98]

Type of dose	Benefits	Dose	Products
Low dose (up to 1 kGy)	Inhibition of sprouting	0.05–0.15	Potatoes, onions, garlic, root ginger, yam, etc.
	Insect disinfestation and parasite disinfection	0.15–0.5	Cereals and pulses, fresh and dried fruits, dried fish and meat, fresh pork, etc.
	Delay of physiological processes (e.g., ripening)	0.25–1.0	Fresh fruits and vegetables
Medium dose (1–10 kGy)	Extension of shelf life	1.0–3.0	Fresh fish, strawberries, mushrooms, etc.
	Elimination of spoilage and pathogenic microorganisms	1.0–7.0	Fresh and frozen seafood, raw or frozen poultry and meat, etc.
	Effect on food properties	2.0–7.0	Grapes (increasing juice yield), dehydrated vegetables (reduced cooking time), etc.
High dose (10–50 kGy)	Industrial sterilization (in combination with mild heat)	30–50	Meat, poultry, seafood, prepared foods, sterilized hospital diets
	Decontamination of certain food additives and ingredients	10–50	Spices, enzyme preparations, natural gum, etc.

900 MPa to kill microorganisms in foods. This process also inactivates spoilage of foods, delays the onset of chemical and enzymatic deteriorative processes, and retains the important physical and physiochemical characteristics of foods. HHP has the potential to serve as an important preservation method without degrading vitamins, flavors, and color molecules during the process [58, 103, 104]. Freshness and improved taste with high nutritional value are the peerless characteristics of HPP technology. This process is also environmental friendly, since energy consumption is very low and minimal effluents are required to discharge [105, 106]. The major drawback of this technology is the high capital cost. In addition, limited information and skepticism about this technology also limit the wide application of HPP processes [58, 78, 105].

Mechanism and working principle HP process follows Le Chatelier's principle and isostatic principle [58]. According to Le Chatelier's principle, biochemical and physicochemical phenomena in equilibrium are accompanied by the change in volume and hence influenced by pressure. Regardless of the shape, size, or geometry of the products, the isostatic principle relies on the instant and uniform pressure transmittance throughout food systems [58]. HP processes affect all reactions and structural changes where a change in volume is involved. The combined effect of breaking down and permeabilization of cell membrane kills or inhibits the growth of microorganisms. Vegetative cells are inactivated at 3000 bar pressure (approximate) at ambient temperature, while spore inactivation requires much higher pressure in combination with the temperature rise to 60 °C to 70 °C. Moisture level is extremely important in this context since little effect is noticeable below 40% moisture content [81]. Container processing and bulk processing are two methods of preserving foods under high pressure. Table 14 presents the advantages and limitations of in-container and bulk processing of foods under high pressure.

Pulsed electric field

Pulsed electric field (PEF) food processing is defined as a technique in which food is placed between two electrodes and exposed to a pulsed high voltage field (20–40 kV/cm). Generally, the PEF treatment time is less than one second [84]. Low processing temperature and short residence time of this process allow a highly effective inactivation of microorganisms [107]. PEF processing is much effective to destroy gram-negative bacteria than gram-positive bacteria. Vegetative cells are much sensitive than spores to this process. All cell deaths occur due to the disruption of cell membrane function and electroporation [29]. PEF technology retains taste, flavor, and color of the foods. Furthermore, this technique is not toxic [108]. However, this process has no impact on enzymes and spores. It is also not suitable for conductive materials and only effective to treat liquid foods. This process is energy extensive and may possess environmental risks [72, 109].

Preservation of liquid foods Nonthermal food preservation processes, such as HPP and PEF, are reported to be more effective than thermal processing [110–112]. Microbial inactivation achieved by PEF mainly depends on electric field strength (20–40 kV/cm) and number of pulses produced during processing [112]. It has been found that most of the spoilage and pathogenic microorganisms are sensitive to PEF. However, it is noted that treatment of plant or animal cells require a high field strength and higher energy input, which increases the processing cost. In addition, this kind of field strength may destroy the structure of solid food. Therefore, PEF is more favorable to preserve liquid foods. Microbial inactivation by PEF has been found effective for fruit or vegetable juices, milk, liquid egg, and nutrient broth [107].

Processing parameters Different types of foods are processed using PEF process. Processing parameters of different PEF-treated foods are listed in Table 15.

Biological process: fermentation

Fermentation method uses microorganisms to preserve food. This method involves decomposition of carbohydrates with the action of microorganisms and/or the enzymes [113]. Bacteria, yeasts, and molds are the most common groups of microorganisms involved in fermentation of a wide range of food items, such as dairy products, cereal-based foods, and meat products [114, 115]. Fermentation enhances nutritional value, healthfulness, and digestibility of foods. This is a healthy alternative of many toxic chemical preservatives [116].

Classification of fermentation Fermentation can be spontaneous or induced. There are different types of fermentation used in food processing. Mechanisms of different food fermentation techniques are briefly discussed below:

Alcohol fermentation is the result of yeast action on the simple sugar called 'hexose' converting this into alcohol and carbon dioxide. The quality of fermented products depends on the presence of alcohol. In this process, air is excluded from the product to avoid the action of aerobic microorganisms, such as the acetobacter. This process ensures the longer shelf life of the products. The following equation illustrates alcohol fermentation by conversion of hexose[117]

$$C_6H_{12}O_6 + O_2 = C_2H_5OH + CO_2 \text{Hexose} + \text{Oxygen} = \text{Ethanol} + \text{Carbon dioxide}.$$

Vinegar fermentation takes place after alcohol fermentation. Acetobacter converts alcohol to acetic acid in the presence of excess oxygen [114, 118]. Under this method, food products are preserved as pickles, relishes, etc. [104]. Vinegar fermentation results in acetic acid and water by oxidation of alcohol [114]

$$C_2H_5OH + O_2 = CH_3\,COOH + H_2\,O\,\text{Ethanol} + \text{Oxygen} = \text{Acetic Acid} + \text{Water}.$$

Lactic acid fermentation takes place due to the presence of two types of bacteria: homofermenters and heterofermenters. Homofermenters produce mainly lactic acid, via the glycolytic (Embden–Meyerhof pathway). Heterofermenters produce lactic acid plus appreciable amounts of ethanol, acetate, and carbon dioxide, via the 6-phosphogluconate/phosphoketolase pathway [114].

Table 14 Advantages and disadvantages of in-container processing and bulk processing [81]

In-container processing		Bulk processing	
Advantages	**Limitations**	**Advantages**	**Limitations**
Applicable to all solid and liquid food	Complex materials handling	Simple materials handling	Only suitable for pumpable foods
Minimal risk of post-processing contamination	Little flexibility in choice of container	Greater flexibility in choice of container	Aseptic filling of containers required potential post-processing contamination
Major development needed for high-pressure processing	Greater dead time in use of pressure vessel	Maximum efficiency in use of high-pressure vessel volume	All pressure components in contact with food must have aseptic food design and be suitable for cleaning in place and sterilizing in place
Easier cleaning	–	Minimum vessel dead time (no opening/closing of vessel needed, faster loading/unloading)	–

Table 15 Processing parameters of PEF-treated food products [110, 111]

Product	Processing conditions				
	Electric field strength (kV/cm)	Number of pulses	Duration of pulses (μs)	Temperature of product (°C)	Log reduction (D)
Orange juice	6.7	5	20	45–50	5
Milk	22	20	20	45–50	4.6
Skim milk	45	64	1.8–6	35	2
Yoghurt	23–28	20	100	63	2
Liquid egg	25.8	100	4	37	6
Pea soup	25–33	10–30	2	53–55	4.4
Fluid food	12–25	25	1–100	45–55	Shelf life extended from 3–7 days

Homolactic fermentation—The fermentation of 1 mol of glucose yields two moles of lactic acid

$$C_6H_{12}O_6(\text{Glucose}) \rightarrow 2CH_3CHOHCOOH\ (\text{Lactic Acid}).$$

Heterolactic fermentation—The fermentation of 1 mol of glucose yields 1 mol each of lactic acid, ethanol, and carbon dioxide [114]

$$C_6H_{12}O_6 = CH_3CHOHCOOH + C_2H_5OH + CO_2\text{Glucose} = \text{Lactic Acid} + \text{Ethanol} + \text{Carbon dioxide}.$$

In the fermentation process, different kinds of microorganisms are used exclusively to produce flavor in foods, which are presented in Table 16 [113].

Table 16 Microorganisms used in food processing and flavor compounds produced [113]

Food items	Microorganisms	Flavor compounds produced
Buttermilk	*Streptococcus lactis* *Streptococcus cremoris* *Lactobacillus bulgaricus*	Lactic acid, diacetyl, small amounts of acetaldehyde
Yoghurt	*Streptococcus thermophiles* *Lactobacillus bulgaricus*	Acetaldehyde and diacetyl acetoin
Alcoholic fermented milk	*Saccharomyces sp.* *Lactobacillus sp.*	Ethanol acetoin and diacetyl
Sauerkraut	*Mixed cultures of* *Lactobacillus brevis* *Leuconostoc mesenteroides* *Lactobacillus plantarum*	Acetate and small amounts of short-chain fatty acids
Soybean milk	*Lactobacillus sp.* *Streptococcus thermophiles*	Aldehydes including pentanal
Soya sauce	*Aspergillus oryzae* *Lactobacillus sp.* *Saccharomyces rouxii*	Organic acids, alkyl phenols, and pyrazines
Tempeh	*Rhizopus sp.*	Fatty acid
Bread	*Saccharomyces cerevisiae*	Ethanol
Swiss cheese	*Propionibacterium shermanii*	Propionic acid
Cocoa	*Saccharomyces sp.* *Lactobacillus sp.* *Acetobacter sp.*	Fatty acids and aromatic acids

Chemical processes

Food preservation using chemical reagents is one of the ancient and traditional methods [119]. Effectiveness of this method depends on the concentration and selectivity of the chemical reagents, spoilage-causing organisms, and the physical and chemical characteristics of food items [120]. The global consumption and application of food additives and preservatives are extending. At present (2012 data), North America dominated the food preservative market followed by Asia–Pacific. It is expected that the food preservative market will reach to a volume of $2.7 billion by the end of 2018 [121]. However, using chemical reagents as food additives and preservatives is a sensitive issue because of health concerns [122]. In different countries, the applications chemical preservatives and food additives are monitored and regulated by different acts, rules, and government authorities [119, 123, 124].

Chemical preservatives

Preservatives are defined as the substances capable of inhibiting, retarding, or arresting the growth of microorganisms or any other deterioration resulting from their presence [125]. Food preservatives extend the shelf life of certain food products. Preservatives retard degradation caused by microorganisms and therefore maintain the color, texture, and flavor of the food item [125].

Food preservatives can be classified as natural and artificial. Animals, plants, and microorganisms contain various chemicals which have potential to preserve foods. They also function as antioxidants, flavorings, and antibacterial agents [126]. Table 17 presents different natural reagents with their functions as food preservatives. Artificial preservatives are produced industrially. These can be classified as antimicrobial, antioxidant, and antienzymatic [127]. The classification of artificial preservatives used in food industry is presented in Table 18.

Table 17 Some types of natural preservatives [128]

Natural preservative	Example of food items	Functions
Salt	Salted fish	Salt and sugar draw the water out of microorganisms and retard the growth of microorganisms
Sugar	Jam	
Vinegar	Pickled mango	Vinegar provides an acidic condition which creates an unfavorable condition for microorganisms
Rosemary extract	Mayonnaise, margarine, oils and fats, etc.	Rosemary extracts work as antioxidant

Table 18 Classification of artificial preservatives [44, 128–130]

	Antimicrobial agents	Antioxidants agents	Antienzymatic agents
Definition	Inhibit the growth of undesirable microorganisms (fungi, bacteria, yeast)	Inhibit atmospheric oxidation. Mainly used for the products that contains unsaturated fatty acids, oils, and lipids	Prevent natural ripening process and oxidative deterioration of food by inhibiting the bacteria, parasite, fungi
Mechanism	Creates unfavorable environment for microorganisms by reducing moisture content and increasing acidity	Oxidation of unsaturated fats produces free radicals which can start chain reactions. In this reaction, aldehyde and ketones are produced which results in the rancid taste of foods. Antioxidants terminate these chain reactions by removing free radical intermediates and inhibit other oxidation reactions	Blocks enzymatic processes in the food that continue to metabolize after harvest. Metal chelating agents can remove the metal cofactors that many enzymes need
Applications	Sorbic acid (2,4-hexadienoic acid) and potassium sorbet for the preservation of cheese, bakery products, vegetable-based products, dried fruits, beverages, and other products as well as smoked fish, margarine, salad cream, and mayonnaises.	Butylated hydroxyl anisole, (BHA) for the preservation of butter, lard, meats, beer, baked goods, snacks, potato chips, nut products, dry mix for beverages	Citric acid for the preservation of foods, beverages, dairy products, and pharmaceuticals
	Benzoic acid and sodium benzoate for the preservation of mayonnaises, pickled vegetables, fruit preparation and fruit based drinks, dessert sauces and syrups	Butylated hydroxyl toluene (BHT) in fats and oils processing	EDTA (ethylenediamine tetra acetic acid) in food processing
	Lactic acid for the preservation of meats	Sulfites for the preservation of beer, wines, dried foods	Polyphosphates for the preservation of fresh peeled fruits and vegetables
	Parabens (esters of para-hydroxy benzoic acid) for the preservation of dried meat products, cereal and potato based snacks and confectionary	Vitamin E for the preservation off fruits and vegetables	Polyphosphates for the preservation of fresh peeled fruits and vegetables
	Nitrite (sodium nitrate) for the preservation of meat	Gallates in fats and oils processing	–
	Sulfur dioxide, sodium sulfite for the preservation of dried fruits, certain fruit juices, potatoes, and wines	Ascorbyl palmitate for the preservation of sausages and chicken broths	–

Food additives

The key objectives to use food additives are to improve and maintain nutritional value, to enhance quality, to reduce wastage, to enhance customer acceptability, to make food more readily available, and to facilitate processing food items [131]. Food additives can be either natural or synthetic chemical substances that are used intentionally during processing, packaging, or storage of foods to bring desired changes in food characteristics. Food additives can be divided into two major groups: intentional and incidental. Among these two, intentional additives are strictly controlled by government authority [131]. According to the National Academy of Sciences (1973), additives are prohibited to disguise faulty process, to hide spoilage, damage, or other inferiority, and apparently to deceive consumer. Moreover, if additives cause substantial reduction in nutrition, then their uses are also unaffiliated [131]. Table 19 presents different types of food additives with their possible applications.

Possible health effects of food additives and preservatives

Chemical food additives and preservatives are mostly considered safe, but several of them have negative and potentially life-threatening side effects. For example, nitrates, upon ingestion, are converted to nitrites that can react with hemoglobin to produce met-hemoglobin (aka: met-hemoglobin), a substance that can cause loss of consciousness and death, especially in infants. Different artificial food colorings, such as tartrazine, allura red, ponceau, and benzoate preservatives, have adverse effects on the behavior of infants; these additives are credited as the cause of the hyperactive behaviors of infants [133]. Preservatives also have intolerances among people who have asthma. Sulfites (including sodium bisulfite, sodium meta-bisulfite, and potassium bisulfite) found in wine, beer, and dried fruits are known to trigger asthmatic syndromes and cause migraines in people who are sensitive to them. Sodium nitrate and sodium nitrite are also classified as 'probable carcinogenic elements' to humans by International Agency for Research of Cancer (IARC) [134]. Nitrites and benzoates may have adverse effects on pregnant women. Sodium nitrite intake lowers hemoglobin and hematocrit values of pregnant women. Both benzoate and nitrite induce decrease in serum bilirubin and increase in serum urea. Consequently, the mean weight and length of the fetus get lowered [135]. Nitrites, after ingestion, get converted into nitrosamines, which could be harmful to a fetus [136]. Table 20 discusses the excerpts of negative effects of harmful food preservatives.

Analysis of market economy of preserved foods: global perspective

Food processing industries hold a dominating position in global economy. The processed food market is undergoing constant growth due to technological advancements, increasing demand, and the taste and behavioral pattern of consumers. Both developed and developing countries are opting new food processing and distribution methods responding to this progress [142–144].

The global fruit and vegetable processing industry is expected to grow at an accelerated pace in the upcoming years. Domestic demand for industry products is expected to grow particularly strong, specifically in developing economies, such as China and India. On the other hand, demand in developed economies (such as the USA) is expected to decline at a marginal rate as consumers increasingly replace their consumption of processed fruits and vegetables with fresh produce. Trade in processed fruit and vegetable products is expected to grow at an annualized rate of 3.3% in the next five years (2016–2021); the overall industry revenue is expected to grow at an annualized rate of 3.0% (2016–2021) [145]. Figure 6 represents the present and future trend of vegetable and fruit processing industries in the world.

The developing world produces majority of the world's fresh fruits and vegetables [145]. According to data sourced from the Food and Agriculture Organization of the United Nations, China produces about half of the world's vegetables and one-third of the world's fruits [142, 145]. The production of processed fruits and vegetables occurs in all regions of the globe. However, high-tech, large-scale fruit and vegetable processing operations are concentrated primarily in Europe and Asia [145]. Table 21 represents the contribution of different regions in global processed fruit and vegetable production. Many leading fresh product producing countries often import fresh products from separate countries to meet the demand of their food processing industries. Production in developing nations is also growing to meet the demand of growing population. As a result, the number of industry enterprises and workers are forecast to grow at annualized rates of 2.2 and 1.6%, respectively, till 2017 [145, 146]. After 2019–2020, a decline in the growth of global vegetable and food processing industries is anticipated (Fig. 6) because of the following possible reasons [118, 145, 146]:

Table 19 Some types of food additives [132]

Type of additive	Purpose	Example
Emulsifiers, stabilizers and thickeners	Impart a consistent texture to products; prevent separation of food	Algin, carrageenan
Anticaking agents	Enable products such as table salt to flow freely	Calcium silicate
Nutrients	Enrichment (replacement of nutrients lost during processing) and fortification (adding to the nutritional value of foods)	Folic acid, beta carotene, vitamin D, iron, iodine, etc.
Preservatives	Retard spoiling, prevent fats and oils from becoming rancid, prevent fresh food from turning brown	Nitrates, parabens, BHA, BHT, etc.
Leavening agents	Cause bread and baked goods to rise during baking	Sodium bicarbonate
Flavoring agents	Enhance flavor of foods	Monosodium glutamate (MSG)
Sweeteners	Add sweetness with or without extra calories	Sucrose
Coloring agents	Impart color to foods	Caramel
Fat replacers	Impart texture and creamy 'mouth feel' to food	Cellulose gel

Table 20 Possible negative effects of food preservatives [133, 137–141]

Preservative	Where found	Possible negative effects
Sodium benzoate (E211)	Carbonated drinks, pickles, sauces, certain medicines (even some 'natural and homeopathic' medications for kids)	Aggravates asthma and suspected to be a neurotoxin and carcinogen, may cause fetal abnormalities. Worsens hyperactivity
Sulfur dioxide (E220)	Carbonated drinks, dried fruit juices, cordials, potato products	May induce gastric irritation, nausea, diarrhea, asthma attacks and skin rashes. Destroys vitamin B1. Causes fetal abnormalities and DNA damage in animals
Sodium meta-bisulfite	Preservative and antioxidant	May provoke life-threatening asthma
Potassium nitrate (E249)	Cured meats and canned meat products	May lower oxygen carrying capacity of blood; may combine with other substances to form nitrosamines that are carcinogens
P-hydroxy benzoic acid esters (parabens)	Preserved foods and pharmaceuticals	These compounds exert a weak estrogenic activity. Butyl paraben adversely affects the secretion of testosterone and the function of the male reproductive system
Lactic acid bacteria	Fermented foods	*Listeria monocytogenes* may grow in raw milk, meat, and vegetables during fermentation process. This pathogen is responsible for causing foodborne illness
Mono sodium glutamate (MSG)	All frozen foods, canned tuna and vegetables	Eating too much MSG can cause general weakness, flushing, heart palpitations, or numbness
Aspartame	Used as a low-calorie sweetener in gum, drinks, pudding, and yogurt	It may cause allergy and migraine headache
Sodium nitrite and sodium nitrate	Processed meats and fish to retain red color and avoid botulism	Consuming high amount of bacon, hot-dog, sausage containing nitrites or nitrates may cause type-1 diabetes. The risk is too prominent for pregnant women and children. These salts may also cause irritation to digestive system including mouth, esophagus, and stomach
Trans fat	Deep processed fast foods and certain processed foods	Increase cholesterol level and the risk of heart attack. Contribute to increased inflammation, diabetes, and obesity problems
Sodium sulfite (E221)	Used in wine making and other processed foods	Increase the risk of asthma and in extreme case may cause cardiac arrest
Potassium bromate	White flour, bread, and rolls	This salt is considered as carcinogenic and its presence in bread may cause harmful effects to human
Propyl gallate and tertiary butyl hydroquinone	Processed foods, vegetable oils and meat products	Low doses of propyl gallate can increase the risk of cancer, whereas tertiary butyl hydroquinone increases the incidence of tumors

- Global vegetable and food processing industries are expected to face fierce competition from substitute foods, such as fresh fruit and vegetables;
- Technological change will be relatively minimal and focused on improving processing efficiency; and
- Industry product categories will be well defined with relatively minimal product innovation.

The chilled food market has been showing an upward trend throughout the world, and it reached to a size of 57 billion kilograms in 2015 worth of 11.4 billion euros [108]. Chilled food products include chilled fish/seafood, chilled pizza, chilled ready meals, chilled fresh pasta, sandwiches, salads, chilled meat products, and deli food which includes cured, fermented, and cooked meals [147]. The UK chilled food market had a growth rate of 3.6% in 2014 and expected to grow more than 15% over the next five years [148]. The US frozen food market revenue is expected to reach 70 billion USD by the end of 2024 [106].

Milk and alcoholic beverages mostly constitute pasteurized food market [149]. Presently, almost all the countries consume pasteurized liquid milk. Pasteurized milk constitutes 70% of global liquid milk market [150].

The world beverage market is expected to have an annual growth rate of 1.5% in 2015 [151]. In USA, the total beverage industry was more than USD $1.2 trillion [152]. Asia's beverage market is expected to experience unprecedented growth as well by taking two-thirds of global incremental consumption by 2021. China, India, Indonesia, Pakistan, Thailand, and Vietnam are among the key growing markets, and in a whole Asia is predicted to take 47.2% share of global beverage market in 2021 [153].

USA and Europe hold the major share in sterilized food market. However, the Asian market is also expected to show satisfactory growth in the upcoming years. The global sterilization market was valued at $3.1 billion in 2012 and is forecast to reach $4.2 billion by 2017 at a compound annual growth rate of 6.1% [154].

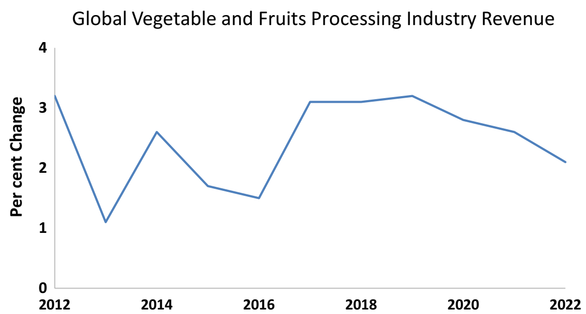

Fig. 6 Present and future trend of vegetable and fruit processing industries [145]

Table 21 Contribution of different regions in global processed fruit and vegetable production [145]

Region	Percentage
Europe	42.3
North Asia	20.1
North America	11.5
South America	9.0
South East Asia	7.2
India and Central Asia	4.7
Africa and Middle East	3.2
Oceania	2.0

Conclusion

One of the major revolutionary inventions of human civilization was acquiring the knowledge to preserve foods as it was the precondition to man to settle down in one place and to develop a society. However, increasing shelf lives of food items without compromising original food properties is still critical and challenging. Food is an organic perishable substance, which is susceptible to spoilage due to microbial, chemical, or physical activities. Different traditional techniques, such as drying, chilling, freezing, and fermentation, had been evolved in the past to preserve foods and to maintain their nutrition value and texture. With time and growing demands, preservation techniques have been improved and modernized. Irradiation, high-pressure food preservation, and pulsed electric field effect are the latest innovations used to increase shelf life of foods. Different chemical reagents have also been introduced as food additives and preservatives. However, there are growing concerns of using chemical additives and preservatives in food items because of possible health hazards.

To meet the growing demand of consumers, food preservation and processing sector has been expanding in a rapid manner. To ensure food safety and long shelf life of foods, it is important to understand food spoilage mechanisms and food preservation techniques. This review has compiled and discussed different food categories, different food spoilage mechanisms, and mechanisms and applications of traditional and advanced food preservation techniques. This article will be useful for the professionals and researchers working on food processing and food safety to develop effective and integrated methods to preserve foods.

Authors contributions

SKA and MMU carried out a major part of the literature review and drafted the manuscript. RR and SMRI carried out literature review for selected sections and helped to revise the manuscript. MSK conceived the study, supervised the research project, coauthored and supervised manuscript preparation, and helped to finalize the manuscript. All authors read and approved the final manuscript.

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Competing interests

The authors declare that they have no competing interests.

Consent for publication

The authors confirm that the content of the manuscript has not been published, or submitted for publication elsewhere.

Ethical approval and consent to participate

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References

1. Rahman MS (eds). Handbook of food preservation. 2nd ed. Food science and technology. Boca Raton: CRC Press; 2007.
2. Nummer BA. Historical origins of food preservation. 2002. http://nchfp.uga.edu/publications/nchfp/factsheets/food_pres_hist.html
3. Blum D. Food that lasts forever, in TIME Magazine. 2012.
4. Freedman DH. The bright, hi-tech future of food preservation, in discover magazine. Kalmbach Publishing Co; 2011.
5. Rahman R. Food preservation. 2014. http://en.banglapedia.org/index.php?title=Food_Preservation.

6. World Food Market Overview Marketing Essay. 2013. ttp://www.ukessays.com/essays/marketing/world-food-market-overview-marketing-essay.php?cref=1.
7. Wilkinson J, Rocha R. Agri-processing and developing countries. Washington, DC: World Bank; 2008.
8. Kar BK. Multi-stakeholder partnership in nutrition: an experience from Bangladesh. Indian J Community Health. 2014;26(1):15–21.
9. Steele R. Understanding and measuring the shelf-life of food, 1st ed. Woodhead Publishing Limited; 2004.
10. Doyle MP. Compendium of the microbiological spoilage of foods and beverages. Food microbiology and food safety. New York: Springer; 2009.
11. Chopra P. Specification of food and nutrition education. 1st ed. New Delhi: APH Publishing Corporation; 2005.
12. Monteiro CA, Levy RB, Claro RM, Castro IR, Cannon G. A new classification of foods based on the extent and purpose of their processing. Cad Saude Publica. 2010;26(11):2039–49.
13. Chopra P. Food and nutrition education. New Delhi: A P H Publishing Corporation; 2005.
14. Carlos Augusto Monteiro RBL, Rafael Moreira Claro, Inês Rugani Ribeiro de Castro, Geoffrey Cannon, A new classification of foods based on the extent and purpose of their processing. Cad Saúde Pública 2010; 6(11):2039–2049
15. Rahman MS. Food properties handbook. New York: CRC Press; 1995.
16. Barbosa-Cánovas GV, Altunaker B, Mejía-Lorío DJ. Freezing of fruits and vegetables. Rome: Food and Agricultural Organization of United Nations; 2005.
17. Kader AA, et al. Modified atmosphere packaging of fruits and vegetables. Crit Rev Food Sci Nutr. 1989;28(1):1–30.
18. White GW, Cakebread SH. The glassy state in certain sugar-containing food products. Int J Food Sci Technol. 1966;1:73–82.
19. Karmas R, Pilar Buera M. Marcus K. Effect of glass transition on rates of nonenzymic browning in food systems. J Agric Food Chem. 1992;40:873–9.
20. Levine H, Slade L. Principles of "cryostabilization" technology from structure/property relationships of carbohydrate/water systems—a review. Cryo Lett. 1988;9(21):21–63.
21. Fennema OR. Food Chemistry. 3rd ed. Marcel Dekker, Inc.; 1996
22. Levine H, Slade L. A polymer physico-chemical approach to the study of commercial starch hydrolysis products (SHPs). Carbohyd Polym. 1981;6:213–44.
23. Reid DS. Optimizing the quality of frozen foods. Food Technol. 1990;44(7):78–82.
24. Roos Y, Karel M. Plasticizing effect of water on thermal behavior and crystallization of amorphous food models. J Food Sci. 1991;56(1):38–43.
25. Fabunmi OA, Osunde ZD, Alabadan BA, Jigam AA. Influence of moisture content and temperature interaction on mechanical properties of DESMA (Novella pentadesma) SEED. J Adv Food Sci Technol. 2015;2(2):81–5.
26. Balasubramanian S, Viswanathan R. Influence of moisture content on physical properties of minor millets. J Food Sci Technol. 2010;47(3):279–84.
27. Barnwal P, et al. Effect of moisture content and residence time on dehulling of flaxseed. J Food Sci Technol. 2010;47(6):662–7.
28. Tianli Y, Jiangbo Z, Yahong Y. Spoilage by alicyclobacillus bacteria in juice and beverage products: chemical, physical, and combined control methods. Compr Rev Food Sci Food Saf. 2014;13(5):771–97.
29. Jay JM. Modern food microbiology. 6th ed. Gaithersburg: Aspen Publishers; 2000.
30. Pitt II, Hocking AD. Fungi and food spoilage. 3rd ed. New York: Springer; 2009.
31. Criado MV, Fernández Pinto VE, Badessari A, Cabral D. Conditions that regulate the growth of moulds inoculated into bottled mineral water. Int J Food Microbiol. 2005;99:343–9.
32. Pitt JI, Hocking AD. Fungi and food spoilage. New York: Springer Science + Business Media; 2009.
33. in't Veld JHH. Microbial and biochemical overview of foods: an overview. Int J Food Microbiol. 1996;33(1):1–18.
34. Van Boekel MA. Kinetic modeling of food quality: a critical review. Compr Rev Food Sci Food Saf. 2008;7:144–58.
35. Enfors S-O. Food microbiology. Stockholm: KTH-Biotechnology; 2008.
36. Rogers LD, Overall CM. proteolytic post translational modification of proteins: proteomic tools and methodology. Mol Cell Proteomics. 2013;12:3532–42.
37. Igarashi Y, Eroshkin A, Gramatikova S, Gramatikoff K, Zhang Y, Smith JW, Osterman AL, Godzik A. CutDB: a proteolytic event database. Oxford J. 2006;35(1):D546–9.
38. Solms J. Taste of amino acids, peptides, and proteins. J Agric Food Chem. 1969;17(4):686–8.
39. Panda H. Herbal Foods and Its Medicinal Values. Delhi: National Institute of Industrial Research; 2003.
40. Desrosier NW, Singh RP. Food preservation. Encyclopaedia Britannica Inc.; 2014. https://www.britannica.com/topic/food-preservation. Cited 4 May 2017.
41. Hoff JE, Castro MD. Chemical composition of potato cell wall. J Agric Food Chem. 1969;17(6):1328–31.
42. Walter RH, Taylor S. The Chemistry and Technology of Pectin. Food Science and Technology, 1st ed. Academic Press; 1991.
43. Rodriguez F, Mesler R. Some drops don't splash. J Colloid Interface Sci. 1984;106(2):347–52.
44. Rahman MS. Handbook of food preservation. 2nd ed. Boca Raton: Taylor and Francis; 2007.
45. Rodriguez-Gonzalez O, et al. Energy requirements for alternative food processing technologies—principles, assumptions, and evaluation of efficiency. Compr Rev Food Sci Food Saf. 2015;14(5):536–54.
46. Drake MA, Drake S, Bodyfelt FW, Clark S, Costello M. The sensory evaluation of dairy products. 2nd ed. New York: Springer; 2008.
47. Ohlsson T, Bengtsson N. Minimal processing technologies in the food industry. 1st ed. Florida: CRC Press; 2002.
48. Karel M, Lund DB. Physical principles of food preservation. 2nd ed. New York: CRC Press; 2003.
49. Berk Z. Food process engineering and technology. Food Science and Technology, 2nd ed. Academic Press; 2013.
50. Rayaguru K, Routray W. Effect of drying conditions on drying kinetics and quality of aromatic *Pandanus amaryllifolius* leaves. J Food Sci Technol. 2010;47(6):668–73.
51. Leniger HA, Beverloo WA. Food Process Engineering. Netherlands: Springer; 1975.
52. Syamaladevi RM, Tang J, Villa-Rojas R, Sablani S, Carter B, Campbell G. Influence of water activity on thermal resistance of microorganisms in low-moisture foods: a review. Compr Rev Food Sci Food Saf. 2016;15(2):353–70.
53. Agrahar-Murugkar D, Jha K. Effect of drying on nutritional and functional quality and electrophoretic pattern of soyflour from sprouted soybean (Glycine max). J Food Sci Technol. 2010;47(5):482–7.
54. Jangam SV, Law CL, Mjumder AS. Drying of foods, vegetables and fruits, vol. 1, 1st ed. Singapore; 2010.
55. Kutz M. Handbook of farm, dairy, and food machinery. 1st ed. New York: William Andrew; 2008.
56. Salvato JA, Nemerow NL, Agardy FJ. Environmental Engineering. 5th ed. New York: Wiley; 2003.
57. Baker CGJ. Industrial drying of foods, 1st ed. Blackie Academic and Professional; 1997.
58. Bhat R, Alias AK, Paliyath G. Progress in food preservation. Hoboken: Wiley; 2012.
59. Sagar VR, Suresh P. Kumar, Recent advances in drying and dehydration of fruits and vegetables: a review. J Food Sci Technol. 2010;47(1):15–26.
60. DeLong D. How to dry foods. Penguin: The Berkley Publishing Group; 1992.
61. Sequeira-Munoza A, Chevalier D, LeBailb A, Ramaswamya HS, Simpson BK. Physicochemical changes induced in carp (Cyprinus carpio) fillets by high pressure processing at low temperature. Innov Food Sci Emerg Technol. 2006;7(1–2):13–8.
62. Mizuta S, Yamada Y, Miyagi T, Yoshinaka R. Histological changes in collagen related to textural development of prawn meat during heat processing. J Food Sci. 2006;64(6):991–5.
63. Kristensen L, Pueslow PP. The effect of processing temperature and addition of mono- and di-valent salts on the heme- nonheme-iron ratio in meat. Food Chem. 2001;73(4):433–9.
64. Baker CGJ, Ranken MD, Kill RC. Food industries manual. 24th ed. New York: Springer; 1997.

65. Shenga E, Singh RP, Yadav AS. Effect of pasteurization of shell egg on its quality characteristics under ambient storage. J Food Sci Technol. 2010;47(4):420–5.
66. Laudan R. Food and nutrition: lifespan, human to pesticides. New York: Marshall Cavendish; 2009.
67. Cavazos-Garduño A, Serrano-Niño JC, Solís-Pacheco JR, Gutierrez-Padilla JA, González-Reynoso O, García HS, Aguilar-Uscanga BR. Effect of pasteurization, freeze-drying and spray drying on the fat globule and lipid profile of human milk. J Food Nutr Res. 2016;4(5):296–302.
68. Brown A. Understanding food: principles and preparation. 3rd ed. Belmont: Wadsworth Publishing; 2007.
69. Arcand Y, Boye JI. Green technologies in food production and processing. 1st ed. New York: Springer; 2012.
70. Farrall AW. Engineering for daily food products. New York: Wiley; 1980.
71. Tamime AY. Dairy fats and related products. 1st ed. West Sussex: Wiley-Blackwell; 2009.
72. Fellows PJ. Food processing technology: principles and practice. 3rd ed. Cambridge: Woodhead Publishing; 2009.
73. Knechtges PL. Food safety: theory and practice. 1st ed. Jones and Bartlett: Burlington; 2012.
74. Heldman DR, Lund DB, Sabliov C. Handbook of food engineering. 2nd ed. Boca Raton: CRC Press; 2007.
75. Kirk-Othmer. Food and feed technology, Vol. 1. New Jersey: Wiley-Interscience; 2007.
76. Tucker GS. Food biodeterioration and preservation. 1st ed. New Jersy: Wiley-Blackwell; 2007.
77. Strumillo C, Kudra T. Thermal processing of bio-materials. Boca Raton: CRC Press; 1998.
78. Grandison AS, Brennan JG. Food processing handbook, vol. 1. 2nd ed. Weinheim: Wiley-VCH; 2011.
79. Potter NN, Hotchkiss JH. Food science. 5th ed. New York: Springer; 1999.
80. Miller GD, Jarvis JK, National Dairy Council, McBean LD. Handbook of dairy foods and nutrition. 3rd edn. Boca Raton: CRC Press; 2006.
81. Ohlsson T, Bengtsson N. Minimal processing technologies in food industry. Cambridge: Woodhead Publication; 2002.
82. George M. Food biodeterioration and preservation. In: Tucker GS, editor. Blackwell Publisher: Singapore; 2008.
83. Velez-Ruiz JF, Rahman MS. Food preservation by freezing. In: Rahman MS, editor. Handbook of food preservation. New York: CRC Press; 1999.
84. Brennan JG. Food processing handbook. Weinheim: WILEY-VCH Verlag GmbH & Co. KGaA; 2006.
85. Ramaswamy HS, Tung MA. A review on predicting freezing times of foods. J Food Process Eng. 1984;7(3):169–203.
86. Pruthi JS. Quick freezing preservation of foods: foods of plant origin. Foods of plant origin. Vol. 2. Mumbai: Allied Publishers Limited; 1999
87. Venugopal V. Seafood processing adding value through quick freezing, retortable packaging and cook chilling. Boca Raton: CRC Press, Taylor & Francis Group; 2006
88. Saravacos G, Kostaropoulous AE. Handbook of food processing equipment. food engineering series. New York: Kluwer Academic/Plenum Publishers; 2002.
89. Indira V, Sudheer KP. Post Harvest technology of horticultural crops. In: Peter KV, editor. Horticulture science. New Delhi: New India Publishing Agency; 2007.
90. Lund MKDB. Physical principles of food preservation. 2nd ed. New York: Taylor & Francis; 2005.
91. Magnussena OM, Hauglandb A, Hemmingsenb AKT, Johansenb S, Nordtvedtb TS. Advances in superchilling of food—process characteristics and product quality. Trends Food Sci Technol. 2008;19(8):418–24.
92. James S. Food biodeterioration and preservation. Singapore: Blackwell; 2008.
93. Light N, Walker A. Cook-chill catering: technology and management. New York: Elsevier Science Publishing co. Inc.; 1990.
94. Richardson P. Improving the thermal processing of foods. England Woodhead Publishing in Food Science and Technology; 2004
95. Arora RK. Food service and catering management. New Delhi: APH Publishing Corporation; 2007.
96. Handbook of Food Science, Technology and Engineering Vol. 03. Taylor & Francis group; 2005
97. Arvanitoyannis IS. Irradiation of food commodities: techniques, applications, detection, legislation, safety and consumer opinion. 1st ed. Burlington: Elsevier; 2010.
98. Sommers B.A.N.a.C.H., Irradiation: food. encyclopedia of agricultural, food, and biological engineering, 2010. p. 864–8.
99. Moniruzzaman M, Alam MK, Biswas SK, Pramanik MK, Islam MM, Uddin GS. Irradiation to ensure safety and quality of fruit salads consumed in Bangladesh. J Food Nutr Res. 2016;4(1):40–5.
100. Heldman DR, Moraru CI. Food encyclopedia of agricultural, food, and biological engineering, 2nd ed. CRC Press; 2010, pp. 869–72.
101. Kanatt SR, Chander R, Sharma A. Effect of radiation processing of lamb meat on its lipids. Food Chem. 2006;97(1):80–6.
102. Smith JS, Pillai S. Irradiation and food safety. Food Technology. 2004;58(11):48–55.
103. Dunne CP. High pressure processing of foods. 1st ed. New York: Blackwell Publishing; 2007.
104. Koutchma T, Popović V, Ros-Polski V, Popielarz A. Effects of ultraviolet light and high-pressure processing on quality and health-related constituents of fresh juice products. Compr Rev Food Sci Food Saf. 2016;15(5):844–67.
105. Nielsen HB, Sonne AM, Grunert KG, Banati D, Pollák-Tóth A, Lakner Z, Olsen NV, Žontar TP, Peterman M. Consumer perception of the use of high-pressure processing and pulsed electric field technologies in food production. Appetite. 2009;52(1):115–26.
106. Yeung CK, Huang SC. Effects of high-pressure processing technique on the quality and shelf life of chinese style sausages. J Food Nutr Res. 2016;4(7):442–7.
107. Sun D-W. Emerging technologies for food processing, 2nd ed. Academic Press; 2014
108. Mohammed MEA, Eissa AA, Aleid SM. Application of pulsed electric field for microorganisms inactivation in date palm fruits. J Food Nutr Res. 2016;4(10):646–52.
109. Mathavi V, Sujatha G, Bhavani Ramya S, Devi BK. New trends in food processing. Int J Adv Eng Technol. 2013;5(2):176–87.
110. Fellows P. Food processing technology: principles and practice, 3rd ed. Woodhead Publishing; 2009
111. Maciej Oziembłowski WK. Pulsed electric fields (PEF) as an unconventional method of food preservation. Polish J Food Nutr Sci. 2005;14(55):31–5.
112. Rahman S, Ahmed J. Handbook of food process design. 1st ed. New Jersy: Wiley-Blackwell; 2012.
113. Shivasankar B. Food processing and preservation. New Delhi: Prentice Hall of India Pvt Limited; 2002.
114. Battock M, Azam-Ali S. Fermented food and vegetables. FAO Agricultural services bulletin-134. Food and Agriculture Organization of the United Nations Rome; 1998.
115. Katz F. Active cultures add function to yoghurt and other foods. Food Technol. 2001;55:46–9.
116. Lewin A. Real food fermentation: preserving whole fresh food with live cultures in your home kitchen, 4th ed. Quarry Books; 2012.
117. Dagoon JD. Applied nutrition and food technology, revised edn. Rex Printing Company Inc.; 1993
118. Azam-Ali, M.M.B.D.S., Fermented fruits and vegetables. A global perspective. Rome: Food and Agriculture Organization of the United Nations.
119. Michael Davidson P, Sofos JN, Larry Branen A. Antimicrobials in Food, 3rd ed. Food Science and Technology. CRC Press; 2005
120. Frank A, Paine HYP. Ai handbook of food packaging. 2nd ed. New York: Springer; 1993.
121. Rohan M. Food preservative market worth $2.7 Billion by 2018. 2009-2014: Dallas.
122. Mursalat M, Rony AH, Rahman AHMS, Islam MN, Khan MS. A critical analysis of artificial fruit ripening: Scientific, legislative and socio-economic aspects. ChE Thoughts. 2013;4(1):6–12.
123. Islam MN, Mursalat M, Khan MS. A review on the legislative aspect of artificial fruit ripening. Agric Food Secur. 2016;5(1):8.
124. Islam MN, et al. A legislative aspect of artificial fruit ripening in a developing country like Bangladesh. Chem Eng Res Bull. 2016;18(1):30–7.
125. Adams MR, Moses MO. Food microbiology. 3rd ed. Cambridge: The Royal Society of Chemistry; 2008, p. 98–99.

126. Msagati TAM. The chemistry of food additives and preservatives. 1st ed. New York: Wiley-Blackwell; 2012.
127. Sati SP, Sati N. Artificial preservatives and their harmful effects: Looking towards nature for safer alternatives. Int J Pharm Sci Res. 2013;4(7):2496–501.
128. Meyer AS, Suhr KI, Nielsen P, Holm F. Natural food preservatives. In: Ohlsson T, Bengtsson N (Eds.) Minimal processing technologies in the food industry, chap 6. Woodhead Publishing; 2002. pp. 124–74.
129. Smith J. Technology of reduced additive foods. 2nd ed. New Jersey: Wiley-Blackwell; 2004.
130. Garg N, Garg KL, Mukerji KG. Laboratory manual of food microbiology. New Delhi: I.K. International Publishing House Pvt. Ltd; 2010
131. de Man JM. Principles of food chemistry. 3rd ed. 1999, New York: Springer
132. Friis RH. Essentials of environmental health. 2nd ed. Burlington: Jones & Bartlett; 2012
133. Kent LT. Food additive side effects. In LIVESTRONG.Com. 2015, leaf.
134. Nogrady B. The hard facts of food additives. ABC Health and Wellbeing; 2013. http://www.abc.net.au/health/features/stories/2013/02/14/3684208.htm. Cited 4 May 2017.
135. Mowafy AR, et al. Effect of food preservatives on mother rats and survival of their offspring. J Egypt Public Health Assoc. 2001;76(3–4):281–95.
136. Food Preservatives. Women's Nutritional Health Care, 2015.
137. Panday RM, Upadhyay SK. Food Additive. In: El-Samragy Y (Ed.) Food Additive, Chap 1. InTech; 2012, p. 1–30.
138. Oishi S. Effects of propyl paraben on the male reproductive system. Food Chem Toxicol. 2002;40(12):1807–13.
139. Soomro AH, Kiran Anwaar TM. Role of Lactic Acid Bacteria (LAB) in food preservation and human health—a review. Pak J Nutr. 2002;1(1):20–4.
140. Marcola J. Top 10 food additives to avoid. Food Matters. Food Matters International Pty Ltd; 2010.
141. Kannall E. The effects of food preservatives on the human body. Chron: The Hearst Newspaper, LLC; 2017. http://livehealthy.chron.com/effects-food-preservatives-human-body-6876.html. Cited 4 May 2017.
142. Regmi A, Gehlhar M. New directions in global food markets. Agriculture Information Bulletin Number 794. Economic Research Service/USDA; 2005.
143. Islam MN, Bint-E-Naser SF, Khan MS. Pesticide food laws and regulations. In: Khan MS, Rahman MS, editors. Pesticide residue in foods: sources, management, and control, 2017, Springer International Publishing: Cham. p. 37–51.
144. Debnath M, Khan MS, Health concerns of pesticides, in pesticide residue in foods: sources, management, and control. In: Khan MS, Rahman MS, editors. Springer International Publishing: Cham; 2017. p. 103–118.
145. Global food and vegetable processing; market research report. IBISWorld Today: United Kingdom; 2017.
146. Global Alcoholic Drinks Industry. Alcoholic Drink Research Market Industry and Statistics 2014 [cited 2014 October 5]; http://www.reportlinker.com/ci02014/Alcoholic-Drink.html.
147. Global Chilled Food Industry. Chilled Food Industry Market Research and Statisitics 2014 [cited 2014 October 5]; http://www.reportlinker.com/ci02046/Chilled-Food.html.
148. UK Chilled Foods Market Driven by Demand for Health Quality Convenience. 2015; http://www.themeatsite.com/articles/2362/uk-chilled-foods-market-driven-by-demand-for-health-quality-convenience/.
149. Tae-Jong K. Pasteurized egg maker eying global markets, in The Korea Times. 2013. South Korea.
150. Analysis and forecast report on pasteurized milk market in China. London: Report Buyer; 2014. http://www.prnewswire.com/news-releases/analysis-and-forecast-report-onpasteurised-milk-market-in-china-250759061.html. Cited 4 May 2017.
151. Angelis AD. Global beverage market. 2013; https://uk.finance.yahoo.com/news/global-beverage-market-000000256.html.
152. Bailey S. alcoholic beverages: a key category of the beverage industry. An Investor's Insight into the Alcoholic Beverage Industry 2015 [cited 2016 October 5]; http://marketrealist.com/2015/03/alcoholic-beverages-key-category-beverage-industry/.
153. Arthur R. Unprecedented growth for asia beverage market in what will global beverage consumption look like in 2021? Region by region data. France: William Reed Business Media; 2016.
154. Rohan M. Global sterilization equipment market worth $4.2 billion by 2017. 2009–2014: Dallas.