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Food Preservation and Processing Methods

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Introduction

Innovation, sustainability and safety have become the main foci of the modern food industry. Food preservation involves the actions taken to maintain foods with the desired properties or nature for a desired time frame (Rahman, 2007). For example, a fresh sandwich has a shelf-life of about 1 day, whereas canned vegetables have a shelf-life of at least 1 year. First it is important to identify the properties or characteristics one wants to preserve. A property may be important in one product but detrimental in others. For example, collapse and pore formation occurs during the drying of foods, and this can be desirable or undesirable depending on the desired quality of the dried product. Two illustrations will suffice: firstly, crust formation is desirable for long bowl life in the case of breakfast cereal ingredients, whereas quick rehydration is necessary (i.e. no crust and open pores) for instant soup ingredients; and secondly, consumers expect apple juice to be clear whereas orange juice can be cloudy. In the case of preservation and safety we want to eliminate pathogenic and spoilage bacteria, whereas in the case of yoghurt we want to preserve the beneficial lactic acid bacteria.

The preservation and processing of food is not as simple or straightforward as it was in the past: it is now progressing from an art to a highly interdisciplinary science. A

Handbook of Food Process Design, First Edition. Edited by Jasim Ahmed and Mohammad Shafiur Rahman.

number of new preservation techniques are being developed to satisfy the current demands of economic preservation and consumer satisfaction with regard to nutritional and sensory aspects, convenience, safety, absence of chemical preservatives, low price, and environmental safety. The ultimate success of the food industry lies in the timely adoption and efficient implementation of the emerging new technologies to satisfy the present and future demands of consumers. The preservation method is mainly based on the types of food that need to be prepared or formulated. The factors that should be considered before selecting a preservation process include the desired quality of the product, the economics of the process, and the environmental impact of the methods. Food industry waste is now also of concern to both enforcement authorities and consumers. Food waste is not only an economic loss, but also has an impact on the environment. It is important to make every effort to minimize waste from the food industry, to set up effective recycling systems, and to implement suitable systems for value-added products.

Purpose of Food Preservation

The main reasons for food preservation are to overcome inappropriate planning in agriculture, to produce value-added products, and to provide variation in the diet (Rahman, 2007). The agricultural industry produces raw food materials in different sectors. Inadequate management or improper planning in agricultural production can be overcome by avoiding inappropriate areas, times, and amounts of raw food materials as well as by increasing storage life using simple methods of preservation. Value-added food products can provide better-quality foods in terms of improved nutritional, functional, convenience and sensory properties. Consumer demand for healthier and more convenient foods also affects the way that food is preserved. Eating should be pleasurable to the consumer, and not be boring. People like to eat a wide variety of foods with different tastes and flavors. Variation in the diet is important, particularly in underdeveloped countries in order to reduce reliance on a specific type of grain (i.e. rice or wheat). In addition food preservation, storage and distribution are also important factors in achieving food security. In food preservation, the important points that need to be considered are desired quality, desired shelf-life, and target consumers.

Desired Quality

In all cases, safety is the first attribute, followed by quality. Product quality attributes can be quite varied, such as appearance and sensory or microbial characteristics. Loss of quality is very dependent on the type of food and composition, formulation (for manufactured foods), packaging, and storage conditions (Singh, 1994). Loss of quality can be minimized at any stage of food harvesting, processing, distribution, and storage. When a preservation method fails, the consequences are wide-ranging, from the food becoming extremely hazardous to minor deterioration such as loss of color (Gould, 1989).

Desired Shelf-life

One of the the most important factors to consider when preserving a food product is the length of time before it becomes unsuitable for consumption (i.e. its shelf-life). Shelf-life is determined by the manufacturer and recommends the length of time that products can be stored during which the quality remains acceptable under specified conditions of distribution, storage, and display. A product that has passed its shelf-life might still be safe, but quality is no longer guaranteed. The best-before date is shorter than the shelf-life by a good margin. Hence, it is usually safe to consume a product after the best-before date, provided the product has been stored under the recommended conditions, but it may begin to lose its optimum flavor and texture.

In studying the shelf-life of foods, it is important to measure the rate of change of a given quality attribute (Singh, 1994). Product quality can be defined using many factors, including appearance, yield, eating characteristics, and microbial characteristics, but ultimately the product must provide a pleasurable experience for the consumer (Sebranek, 1996). Loss of quality is very dependent on the food type and composition, formulation (for manufactured foods), packaging, and storage conditions (Gould, 1989). Loss of quality can be minimized at any stage and thus quality depends on the overall control of the processing chain. The required length of preservation depends on the purpose. In many cases, very prolonged storage or shelf-life is not required, which simplifies both transport and marketing of the foodstuff. For example, prepared meals for lunch need a shelf-life of only one or even half a day. In this case there is no point in ensuring preservation of the product for weeks or months. In other cases very long shelf-lives up to 3–5 years may be required, for example foods for space travelers, and food storage during wars.

Target Consumers

It is important to know for whom the preserved food is being produced. Nutritional requirements and food restrictions apply to different population groups. Food poisoning can be fatal, especially in infants, pregnant women, the elderly, and those with depressed immune systems. The legal aspects of food preservation are different in foods produced for human or animal consumption. Thus, it is necessary to consider the group for whom the products are being manufactured.

Food Preservation Methods

At present different methods of food preservation are available for the food industry. Based on the mode of action, the major food preservation techniques can be

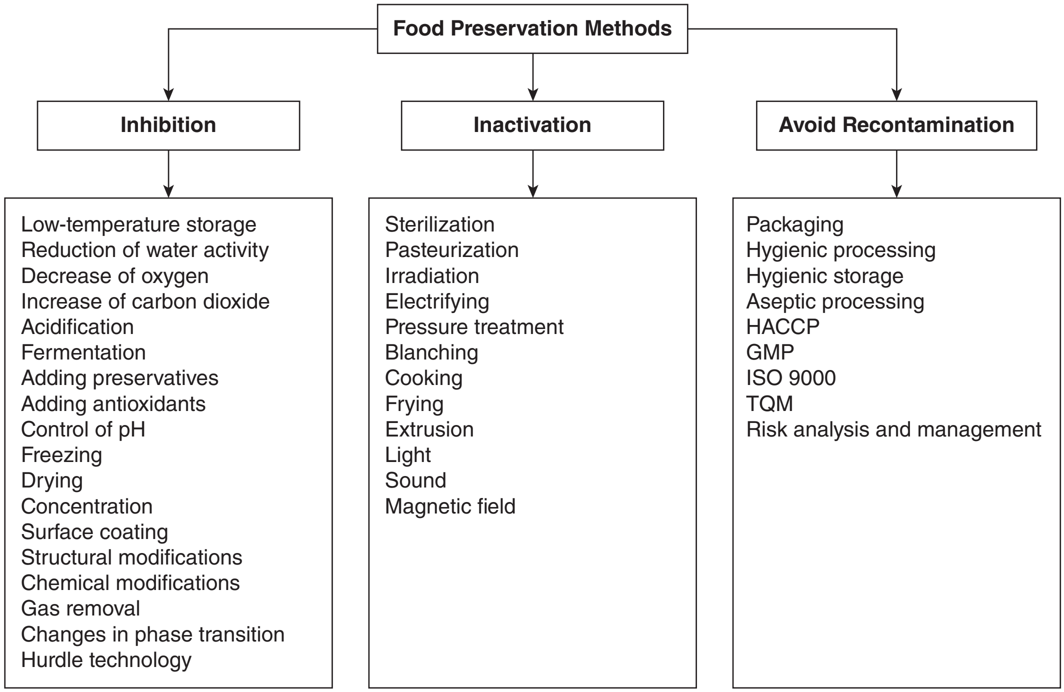

Figure 1.1 Major food preservation techniques. (From Gould, 1989, 1995.)

categorized as (i) slowing down or inhibiting chemical deterioration and microbial growth, (ii) directly inactivating bacteria, yeasts, molds, or enzymes, and (iii) avoiding recontamination before and after processing (Gould, 1989, 1995). A number of techniques or methods from the above categories are shown in Figure 1.1. In many cases it would be very difficult to make a clear distinction between inhibition and inactivation. Take, for example, preservation by drying and freezing. Although the main purpose of freezing and drying is to control the growth of microorganisms during storage, there is also some destruction of microorganisms. Freezing causes the apparent death of 10–60% of the viable microbial population and this gradually increases during storage. The following sections summarize food preservation methods (reviewed by Rahman, 2007).

Inhibition

Methods based on inhibition include those that rely on control of the environment (e.g. temperature control), those that result from particular methods of processing (e.g. microstructural control), and those that depend on the intrinsic properties of particular foods (e.g. control by adjustment of water activity or pH) (Gould, 1995). The danger zone for microbial growth is considered to be between 5 and 60 °C; thus food products chilled and stored at a temperature below 5 °C is one of the most popular methods of food preservation.

Use of Chemicals

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

Many legally permitted preservatives in foods are organic acids and esters, including sulfites, nitrites, acetic acid, citric acid, lactic acid, sorbic acid, benzoic acid, sodium diacetate, sodium benzoate, methylparaben, ethylparaben, propylparaben, and sodium propionate (Silliker *et al*. 1980). When a weak acid is dissolved in water, an equilibrium is established between undissociated acid molecules and charged anions, the proportion of undissociated acid increasing with lower pH. The currently accepted theory of preservative action suggests inhibition via depression of internal pH. Undissociated acid molecules are lipophilic and pass readily through the plasma membrane by diffusion. In the cytoplasm (pH approximately 7.0), acid molecules dissociate into charged anions and protons. These cannot pass across the lipid bilayer and accumulate in the cytoplasm, thus lowering pH and inhibiting metabolism (Krebs *et al*. 1983). There are several limitations to the value of organic acids as microbial inhibitors in foods: they are usually ineffective when initial levels of microorganisms are high; many microorganisms use organic acids as metabolizable carbon sources; there is inherent variability in resistance of individual strains; and the degree of resistance may also depend on the conditions (Silliker *et al*. 1980).

Nitrites and nitrates are used in many foods as preservatives and functional ingredients. They are critical components in the curing of meat, and are known to be multifunctional food additives and potent antioxidants. Many plants contain compounds that have some antimicrobial activity, collectively referred to as 'green chemicals' or 'biopreservatives' (Smid and Gorris, 1999). Interest in naturally occurring antimicrobial systems has expanded in recent years in response to consumers' requirements for fresher, more natural additive-free foods (Gould, 1995). A range of herbs and spices are known to possess antibacterial activity as a consequence of their chemical composition. Antimicrobial agents can occur in foods of both animal and vegetable origin. Herbs and spices have been used for centuries by many cultures to improve the flavor and aroma of foods. Essential oils show antimicrobial properties, and are defined by Hargreaves as a group of odorous principles, soluble in alcohol and to a limited extent in water, consisting of a mixture of esters, aldehydes, ketones, and terpenes. They not only provide flavor to the product, but also act as preservatives. Scientific studies have identified the active antimicrobial agents of many herbs and spices. These include eugenol in cloves, allicin in garlic, cinnamic aldehyde and eugenol in cinnamon, allyl isothiocyanate in mustard, eugenol and thymol in sage, and isothymol and thymol in oregano (Mothershaw and Al-Ruzeiki, 2001).

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

Hydrogen ion concentration, measured as pH, is a controlling factor in regulating many chemical, biochemical, and microbiological reactions. Foods with pH below 4.5 are considered low-risk foods, and need less severe heat treatment. Microorganisms require water, nutrients, and appropriate temperature and pH levels for growth. Below about pH 4.2 most food-poisoning microorganisms are well controlled, but microorganisms such as lactic acid bacteria and many species of yeast and molds grow at pH values well below this. Many weak lipophilic organic acids act synergistically at low pH to inhibit microbial growth. Thus, propionic, sorbic, and benzoic acids are very useful food preservatives. The efficacy of acids depends to a large extent on their ability to equilibrate, in their undissociated forms, across the microbial cell membrane and, in doing so, interfere with the pH gradient that is normally maintained between the inside (cytoplasm) of the cell and the food matrix surrounding it. In addition to weak lipophilic acids, other preservatives widely used in foods include esters of benzoic acid, which are effective at higher pH values than organic acids. Inorganic acids such as sulfate and nitrite are most effective at reduced pH values, like organic acids. While these preservatives are employed at low levels (hundreds to thousands of ppm), the acids used principally as acidulants are often employed at percentage levels (Booth and Kroll, 1989).

The pH affects not only the growth of microorganisms, but also affects other components and processes, such as enzyme stability, gel formation, and stability of proteins and vitamins. Antimicrobial enzymes also have current applications and further future potential in the food industry. Fuglsang *et al*. (1995) pointed out that the potential of these enzymes in food preservation is still far from realized at present.

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

When a chemical is used in preservation, the main question concerns its safety, and a risk–benefit analysis should be carried out. Antimicrobial agents or preservatives are diverse in nature, but legal, toxicological, marketing, and consumer considerations have created a trend such that the number of preservatives, and their concentration in particular foods, are diminishing rather than increasing (Fuglsang *et al*. 1995).

Control of Water and Structure

Many physical modifications are made in ingredients or foods during preservation. Such modifications can also improve the sensory, nutritional, and functional properties of foods. Changes experienced by foods during processing include glass formation, crystallization, caking, cracking, stickiness, oxidation, gelatinization, pore formation, and collapse. Through precise knowledge and understanding of such modifications, one can develop safe high-quality foods for consumption (Rahman, 2007).

The concepts of water activity, glass transition and state diagram are clearly reviewed by Rahman (2006, 2009, 2010). In the 1950s scientists began to discover the existence of a relationship between the water contained in a food and its relative tendency to spoil (Scott, 1953). It was observed that the active water could be much more important to the stability of a food than the total amount of water present. Thus, it is possible to develop generalized rules or limits for the stability of foods using water activity. For example, there is a critical water activity level below which no microorganisms can grow. Pathogenic bacteria cannot grow below a water activity of 0.85, whereas yeasts and molds are more tolerant to reduced water activity, but usually no growth occurs below a water activity of about 0.6. It has been widely accepted that the concept of water activity is a valuable tool for determining microbial stability (Chirife and Buera, 1996). A complete discussion of the microbial response to low water activity has been presented by Rahman (2009).

A food product is the most stable at its "monolayer moisture" content, which varies with the chemical composition, structure and environmental conditions, such as temperature. The BET (Brunauer–Emmet–Teller) monolayer value can be determined from the well-known BET equation. The BET-monolayer estimation is an effective method for estimating the amount of water molecules bound to specific polar sites in a food matrix and it does not simply apply to the product surface. A more detailed explanation of the BET-monolayer, including estimation and validity, was recently provided by Rahman and Al-Belushi (2006). In general the rule of the water activity concept is that food products are most stable at their "BET-monolayer moisture" content or "BET-monolayer water activity" and unstable above or below BET-monolayer. In many other instances it has been shown that optimal water content for stability is not exactly the BET-monolayer. The reason for this variation is due to the fact that the BET theory of adsorption was developed based on many simplified

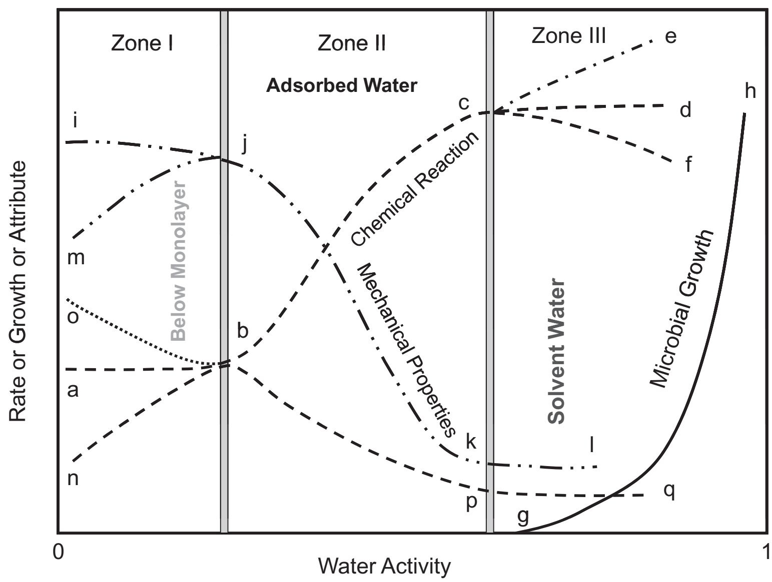

Figure 1.2 Stability diagram based on the water activity concept. gh, microbial growth trend; oa, ab, nb, chemical reaction trends below BET-monolayer; bc, bp, chemical reaction trends in the adsorbed water; ce, cd, cf, pq, chemical reaction trends in the solvent water region; ij, mj, mechanical properties trends below BET-monolayer; jk, mechanical properties trend in the adsorbed water region; ki, mechanical properties trend in the solvent water region. (From Rahman, 2010, courtesy of Elsevier.)

assumptions that are not realistic when food is considered. One of the earlier food stability maps based on the water activity concept contained growth of microorganisms and different types of biochemical reactions (Labuza *et al*. 1972). The updated food stability map based on the water activity is presented in Figure 1.2 (Rahman, 2010). In this present map, the trends of microbial growth, biochemical reactions and mechanical characteristics are presented in the three zones of water activity. This stability map indicates that different types of dynamics in reaction rates can happen as a function of water activity.

The limitations of the water activity concept have been identified by Rahman (2010) as follows:

1. Water activity is defined at equilibrium, whereas foods may not be in a state of equilibrium, for example low- and intermediate-moisture foods can be in amorphous, glass, crystallized, and semi-crystallized states.
2. The critical limits of water activity may also be shifted to higher or lower levels by other factors, such as pH, salt, antimicrobial agents, heat treatment, electromagnetic radiation, and temperature.

3. The nature of the solute used to reduce water activity also plays an important role, for example some solutes are more inhibiting or antimicrobial than others even at the same water activity (so-called specific solute effect).
4. The water activity concept does not indicate exactly when molecular mobility starts, although nuclear magnetic resonance (NMR) and other spectroscopic signals could be related to the water activity. It only provides information on the amount of strongly bound and free water and an indication of their reactivity.
5. The shift of water activity with temperature is relatively very low, whereas in most cases reaction rates are significantly affected by temperature.
6. Many physical changes, such as crystallization, caking, stickiness, gelatinization, and diffusivity, cannot be explained based on water activity alone.

These limitations would not invalidate the concept completely but rather make it difficult to apply universally. However, a stability map could be developed by individually considering different factors that influence stability, as shown in Figure 1.2. In order to find alternative models, the glass transition concept was put forward.

Glassy materials have been known for centuries but it was only in the1980s that the technology started to be purposefully applied to foods and a scientific understanding of these systems started to evolve (Ferry, 1991). A low glass transition means that at room or mouth temperature, the food is soft and relatively plastic, and at higher temperatures it may even flow. In contrast, a food with a high glass transition temperature is hard and brittle at ambient temperature. Early attempts to describe glassy phenomena concluded that glass is a liquid that has lost its ability to flow in a short time frame; thus instead of taking the shape of its container, glass itself can serve as the container for liquids. Food materials are in an amorphous or non-crystalline state below the glass transition temperature and are rigid and brittle. Glasses are not crystalline with a regular structure, but retain the disorder of the liquid state. Physically it is a solid but it more closely resembles a thermodynamic liquid. Molecular mobility increases 100-fold above glass transition. In kinetic terms, Angell (1988) described a glass as any liquid or supercooled liquid whose viscosity is between 10^{12} and 10^{13} Pa·s, thus effectively behaving like a solid, which is able to support its own weight against flow due to gravity. To put this viscosity into context, a supercooled liquid with a viscosity of 10^{14} Pa·s would flow at 10^{-14} m·s^{-1} in the glassy state compared with the flow rate of a typical liquid, which is in the order of 10 m·s^{-1}. In other words, a glass is a liquid that flows about 30 μm in a century (Buitink and Leprince, 2004).

The early papers concerning glass transition in food and biological systems appeared in the literature in the 1960s (White and Cakebread, 1966; Luyet and Rasmussen, 1968). White and Cakebread (1966) first highlighted the importance of the glassy state of food in determining its stability. They were perhaps the first food scientists to discuss the importance of the glassy and rubbery states in relationship to the collapse of a number of high solids systems. The significant applications of the glass transition concept in the 1980s emerged in food processing when Levine and Slade (1986) and Slade and Levine (1988) identified its major merits and wide-ranging applications.

Foods can be considered very stable in the glassy state, since below glass transition temperatures compounds involved in deterioration reactions take many months or even years to diffuse over molecular distances and approach each other to react (Slade and Levine, 1991). The hypothesis has recently been proposed that this transition greatly influences food stability, as the water in the concentrated phase becomes kinetically immobilized and therefore does not support or participate in reactions. Formation of a glassy state results in a significant arrest of translational molecular motion, and chemical reactions become very slow. The rules of the glass-transition concept are (i) the food is most stable at and below its glass transition (i.e. T_g, glass transition of solids with unfreezable water, or T_g', glass transition of maximal-freeze-concentrated condition), and (ii) the higher the $T - T_g$ or T/T_g (i.e. above glass transition), the higher the deterioration or reaction rates. It is very interesting that this concept has been so widely tested in foods. In many instances, the glass transition concept does not work alone, and thus it is now recommended that both the water activity and glass transition concepts are used in assessing processability, deterioration, food stability, and shelf-life predictions. After analyzing data from the literature, Chirife and Buera (1996) concluded that the glass transition concept presently offered a better alternative to the concept of water activity as a predictor of microbial growth in foods.

The state diagram is a stability map of different phases and states of a food as a function of water or solids content and temperature. A state diagram contains mainly the glass line, the freezing curve, and the intersection of these lines as T_g' (in this chapter it is defined as T_g'''). The main advantages of drawing a map are to help in understanding the complex changes that occur when the water content and temperature of a food are changed. It also assists in identifying a food's stability during storage as well as selecting a suitable temperature and moisture content for processing. The recent state diagram is shown in Figure 1.3 (Rahman, 2010).

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

Freezing changes the physical state of a substance by changing water into ice when energy is removed in the form of cooling below freezing temperature. Usually the temperature is further reduced to storage level at −18 °C. Microbial growth is completely inhibited below −18 °C, and both enzymatic and non-enzymatic changes continue at much slower rates during frozen storage. There is a slow progressive change

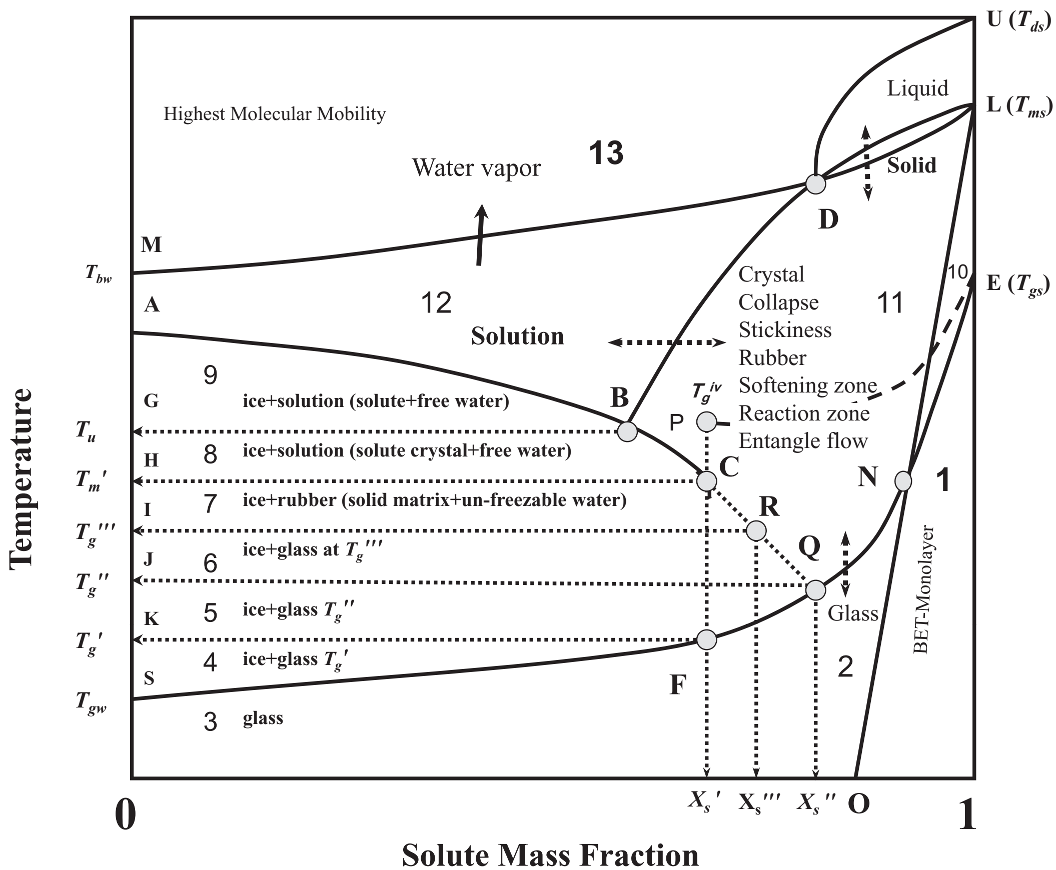

Figure 1.3 State diagram showing different regions and state of foods. (From Rahman, 2010, courtesy of Elsevier.)

in organoleptic quality during storage. Freezing is more popular than drying due to its ability to retain the quality of freshness in the food.

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

Gums and gels, such as casein, guar gum, agar, carrageenan, and pectin, are also used in food products to provide desired structure and functionality to products. These are extremely important for textural attributes, such as creaminess and oiliness of formulated products, and foods that mimic fat4.

Control of Atmosphere

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

Inactivation

Use of Heat Energy

Modern processing developed at the end of the 1700s when the Napoleonic wars raged. As Napoleon pushed forward into Russia, his army was suffering more casualties from scurvy, malnutrition, and starvation. The French government offered 12 000 francs to anyone who could develop a method of preserving food. Nicolas Appert took up the challenge. He had a theory that if fresh foods were put in airtight containers and sufficient heat applied, then the food would last longer. Appert packed his foods in bottles, corked them, and submerged them in boiling water, thus preserving them without an understanding of bacterial spoilage. After 14 years of experimentation, in 1809 he won the prize and this was given to him by Napoleon himself. A theoretical understanding of the benefits of canning did not come until Louis Pasteur observed the relationships between microorganisms and food spoilage some 50 years later (Rahman, 2009).

In earlier times, mostly heat was used for inactivation. Thermal inactivation is still the most widely used process for food preservation. The advantages of using heat for food preservation are that heat is safe and chemical-free, it provides tender cooked flavors and taste, the majority of spoilage microorganisms are heat labile, and thermally processed foods, when packed in sterile containers, have a very long shelf-life.

The main disadvantages of using heat are that overcooking may lead to textural disintegration and an undesirable cooked flavor, and that nutritional deterioration results from high temperature processing. The main heat treatment processes include pasteurization, sterilization, cooking, extrusion, and frying. Recently, more electro-technologies are being used and this will expand further in the future.

Use of High Pressure and Ultrasound

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

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

Use of Electricity

Many different forms of electrical energy are used in food preservation, for example ohmic heating, microwave heating, low electric field stimulation, high-voltage arc discharge, and high-intensity pulsed electric field. *Ohmic heating* is one of the earliest forms of electricity applied to food pasteurization. This method relies on the heat generated in food products as a result of electrical resistance when an electric current is passed through them. In conventional heating methods, heating travels from a heated surface to the product interior by means of both convection and conduction, which is time-consuming, especially with longer convection or conduction paths. Electro-resistive or ohmic heating is volumetric by nature, and thus has the potential to reduce overprocessing. It provides rapid and even or uniform heating, providing less thermal damage and increased energy efficiency. *Microwave heating* has been extensively applied in everyday households and the food industry, but the low penetration depth of microwaves into solid food causes thermal non-uniformity. *Low electric field stimulation* has been explored as a method of bacterial control of meat. The mechanism of microbial inactivation by an electric field was first proposed by Pareilleux and Sicard (1970). The plasma membranes of cells become permeable to small molecules after being exposed to an electric field, and permeation then causes swelling and eventual rupture of the cell membrane. The reversible or irreversible rupture (or electroporation) of a cell membrane depends on factors such as intensity of the electric field, number of pulses, and duration of pulses. This new electro-heating could be used to develop new products with diversified functionality.

Use of Radiation

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

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

Use of Magnetic Fields

Magnetism is a phenomenon by which materials exert an attractive or repulsive force on other materials. The origin of magnetism lies in the orbital and spin motions of electrons, and how the electrons interact with each other. Magnetic fields may be homogeneous or heterogeneous, and can be in static and pulsed mode. Magnetic fields have potential in pasteurization and sterilization, and in enhancing other processes in food preservation, such as damage to and death of parasites, and isolation and separation of protein (Ahmed and Ramaswamy, 2007).

Avoid Recontamination

In addition to the direct approach, other measures such as packaging and quality management tools need to be implemented in the preservation process to avoid contamination or recontamination. Although these measures are not preservation techniques, they play an important role in producing high-quality safe food. With respect to the procedures that restrict the access of microorganisms to foods, the employment of aseptic packaging techniques for thermally processed foods has expanded greatly in recent years, both in the numbers of applications and in the numbers of alternative techniques commonly available (Gould, 1995). The new concepts of packaging include one-way transfer of gases away from the product or the absorption of gases detrimental to the product, antimicrobials in packaging, release of preservatives from controlled-release surfaces, oxygen scavengers, carbon dioxide generators, absorbers or scavengers of odors, and absorption of selected wavelengths of light, capabilities for controlled automatic switching, edible and biodegradable packaging. Food safety is now the highest priority. Recently, the concepts of Hazard Analysis and Critical Control Point (HACCP), ISO 9000, Good Manufacturing Practices (GMP), Standard Operating Procedures (SOP), Hazard and Operability Studies (HAZOP) and Total Quality Management (TQM) have gained attention and these techniques indirectly enhance food preservation.

Recently, the concept of hurdle technology or combined methods of preservation has gained attention. The microbial stability and safety of most traditional and novel foods is based on a combination of several preservative factors (called hurdles), which microorganisms present in the food are unable to overcome. This is illustrated by the so-called hurdle effect, first introduced by Leistner and his coworkers. He acknowledged that the hurdle concept illustrates only the well-known fact that the complex interactions of temperature, water activity, pH, and redox potential are significant for the microbial stability of foods. With respect to procedures that slow down or prevent the growth of microorganisms in foods, major successes have been seen and new applications are steadily being made in the use of combination preservation techniques or hurdle technology (Leistner, 2007).

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