Appendix B

Bask Food Preservation and Deterioration Modes

INTRODUCTION

As pointed out in chapter V, in order to establish a fairly accurate open date for a particular food, one needs to know how that food deteriorates. This appendix contains an in-depth look at the various modes of deterioration and how they impact on open dating. It specifically describes the general modes of deterioration leading to the quality and nutritional losses and types of preservation used to slow down the modes.

MAJOR MODES OF FOOD DETERIORATION

Biological Decay-Preharvest

Prior to harvest and slaughter, foods—whether animal or vegetable—are subjected to a myriad of microbiological diseases, including viruses, molds, yeasts, and bacteria, In addition, some foods before harvest can be eaten by insects, birds, or rodents, or become prone to disease. For plants, competition by weeds can result in poor quality. Controls for such ravages can include pesticides, herbicides, rodenticides, weeding machines, and livestock antibiotics.

Preharvest deterioration as such is not generally considered in open shelf-life dating. However, if food is subject to damage, its initial quality will be less. Since processing does not make low-quality foods better, overall shelf life would be less after slaughter or harvest, as compared with undamaged foods,

Senescence (Aging)

Once a fruit, vegetable, cereal grain, or animal product is harvested or slaughtered, it is separated from its source of nutrients and water. Since it is still a viable living system, the enzymes continue to operate and utilize the carbohydrate and nutrient stores. For fruits, this process can be of benefit because postharvest damage can be repaired. More importantly, fruits can be picked prior to optimum maturity and transported long distances to the marketplace and home, during which time they develop into a high-quality product, If the fruits were picked at optimum ripeness, they could rot before consumption during this transportation. This biochemical process also operates in the aging of meat to achieve the desired degree of tenderness. However, the state of the preslaughter animal is very important and affects the final product quality,

Eventually, though, for all foods, postharvest enzymatic processes lead to degradation of sensory quality, including loss of color, flavor, nutrients, and texture. In addition, the breakdown products themselves damage the tissues such that the decaying process becomes more rapid. To prevent this deterioration, three major control methods can be used: 1) lowering temperature, which slows the rate of the reaction; 2) raising the temperature, which denatures the enzymes and makes them inactive but changes the sensory quality of the foods; and 3) removing or binding water to reduce water availability (or water activity, a_w), which reduces the ability of the en-

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zymes to operate. Other control methods are addition of acid, thereby lowering pH; reduction of oxygen level or increase of carbon dioxide (CO_2), which slows the reactions; and genetic manipulation of the food to altogether prevent the reactions. With respect to open dating, the effects of aging are important in determining shelf life of fresh fruits and vegetables; whole grain cereals; fresh meat, poultry, and fish; and, to some degree, dairy products.

Microbiological Decay

Micro-organisms are responsible for quality loss of many foods, especially fresh ones. The reason is twofold: I) microbes are everywhere in the environment and can grow very rapidly, and 2) after a food is harvested or slaughtered, it loses to some degree the ability to fight off microbial attack, If the food is physically damaged—even by normal trimming and cutting—it becomes more susceptible to attack,

As noted, microbes can grow rapidly on foods. Starting with one microbe that divides every 10 minutes, in 5 hours (if the nutrients were available), there would be over 1 billion microbes. Much of the same controls used for enzymes can also be used for microbes:

- lower temperature to slow growth,
- raise temperature to kill microbes,
- remove or bind water to slow or prevent their growth,
- lower pH to slow or stop their growth by adding acid or by natural fermentation,
- control oxygen (O_2) level to control population or increase CO_2 level, and
- manipulate food composition to remove nutrients needed by the microbes.

Because in some cases the above methods change the food into a form not desired by the consumer or the method is not adequate to extend shelf life, some chemical means of preservation must be used to slow the growth or kill the micro-organisms. Examples are calcium propionate in bread; sodium benzoate in some soft drinks; and natural fermentation that produces alcohol, such as making wine from grapes. Usually only small amounts of the chemicals are used, so that they will have no ill effect on the consumer.

Knowledge of how environmental conditions affect the growth rate of microbes is very important in predicting shelf life, and thus determining the open dating of many foods including:

- fresh and ground meats and poultry;
- fresh fish;
- dairy products such as milk, cheese, and yogurt;
- cured meats such as hot dogs, bacon, and salami;
- pasteurized fruit drinks:
- fruits and vegetables; and
- whole grains.

A second and more serious problem with micro-organisms is the fact that some are pathogenic to humans—that is, they either cause an infection when ingested or while growing produce chemicals in the food that are toxic to humans. Most food processes are designed to ensure against contamination with pathogens or growth of the pathogen after processing, For example, fermentation of foods with useful microbes produces alcohol or acid that prevents the growth of pathogens. Some of the major micro-organisms pathogenic to humans in foods are:

- Intoxicants
  - —*Staphylococcus aureus,*
  - —*Clostridium botulinum,*
  - —*Clostridium perfringens, and*
  - —*Aspergillus flavus.*
- Infectious
  - —*Salmonellae* species, and
  - —*Escherichia coli* strains.

In most cases, temperatures below 7° C, food with a water availability of less than 80-percent relative humidity (a_w or water activity of 0.80), and a pH of less than 4,5 are sufficient conditions to prevent the growth of pathogens. Open dating should not be based on the growth of these organisms, since the manufacture and subsequent handling and distribution should ensure absolute control of these pathogens. Unfortunately, if the latter is not done, consumers may have a false sense of security that a food consumed before its sell-by or use-by date is safe when in fact it could cause food poisoning. This fact points to a must in educating the consumer that open dating is not an absolute assurance of food quality or food safety,

Chemical Deterioration

During the processing of foods, tissue damage occurs that causes the release of various food chemical constituents into the cellular fluid environment. These chemicals can then react with each other or with external factors to lead to deterioration of the food and result in a shortening of shelf life, Although many different reactions are important that lead to quality and nutrient loss, the major ones are classified below.

Enzymatic. As mentioned earlier, normal post-harvest enzymatic reactions can lead to a loss in food quality and shelf life. In addition, destruction of cell tissues releases enzymes that can lead to further deterioration. For example, lipoxidase enzymes released from cell organelles called mitochondria can attack lipids and cause rancidity. Similarly, the polyphenol oxidase enzyme can react with some cell constituents and oxygen, causing a brown color, which is typically seen as a deterioration reaction in bruised or cut fruits such as apples or bananas, These reactions are usually very rapid at room temperature once the food is handled but are controlled in the natural state. The reactions can also occur in the frozen state unless the enzymes are denatured by blanching. Enzymatic reactions are also the major mode of deterioration of many refrigerated doughs, since the flour cannot be heat treated because it results in loss of dough functionality. Control of the enzymatic reactions is the same as was discussed for senescence.

Knowledge of how environmental conditions affect the rate of these reactions is very important in predicting shelf life—and thus for open dating. The major environmental factors are oxygen, water, pH, and temperature. Other enzymatic degradations include color losses and vitamin losses, such as loss of vitamin C in fresh produce.

Lipid oxidation. Many foods contain unsaturated fats that are important in the nutrition of humans. Unfortunately, these fats are subject to direct attack by oxygen through an autocatalytic-free radical mechanism that results in rancid off-flavors, making the food undesirable to consumers. Very little fat has to oxidize for the consumer to detect rancidity and reject a food, even though it may still be edible and nutritious. The free radicals and peroxides produced in this reaction can react and bleach pigments, such as in dried vegetables, if stored for a long time; can destroy vitamins C, E, and A; can result in protein degradation, thus lowering quality as may happen during storage of whole dry milk; can cause darkening of fat at high temperature, as happens in deep-fat frying; and can produce toxic substances during long storage that have been implicated in some animal studies as potential carcinogens.

Thus, knowledge of the rate of lipid oxidation is important in foods where it might be the principal mode of deterioration such as in:

- fried snacks (e. g., chips),
- nuts,
- dried meats/vegetables/f ish/poultry,
- cereals,
- wheat germ,
- frozen vegetables/mea ts/fish/poultry,
- some dairy products,
- semimoist meat products,
- precooked refrigerated meats and fish,
- cured meat and fish,
- coffee,
- cooking and salad oils,
- margarine,
- spices, and
- dried vegetables, such as potatoes and carrots.

Rancidity development can be controlled directly by eliminating oxygen (which is very difficult to do) and by adding antioxidants such as BHA, BHT, and EDTA. The rate of reaction also depends on temperature to some degree (rate increases two to three times for every 10° C increase in storage temperature for dry foods) and on water availability y or water activity (a_w). Foods if too dry or not dried enough are more subject to rancidity. For example, as potato chips gain or lose moisture, they become rancid faster. Moisture gain is more detrimental than loss. Light and trace metals (such as used in fortification) catalyze the reaction. Rancidity can also occur in the frozen state where it is more sensitive to temperature changes (rate increase of 6 to 10 times for a 10° C increase in temperature.)

A knowledge of the rate of these reactions can be used to predict shelf life and thus open date foods. Knowing how fast oxygen permeates a food package is also necessary to predict shelf life. In addition, the consumer must be instructed as to the extent and control of this reaction so as to better maintain the quality and nutritional value of the food in the home.

Nonenzymatic browning (NEB). NEB is another major chemical reaction leading to loss of quality and nutritional value. This reaction occurs between reducing compounds (such as glucose, fructose, and lactose) and amino acids or proteins. In addition, browning can result from heating sugars to very high temperatures (carmelization). In certain cases, the reaction is desirable such as in the toasting of bread: the crust formed in roasting meats; malting of barley for beer and spirits manufacture; and the production of syrups, molasses, and caramel candies.

Undesirable aspects of NEB lead to bitter off-flavors; darkening of light-colored dry products, such as nonfat dry milk; loss of protein volubility; toughening of protein foods; and, most significantly, a decrease in protein nutritional quality caused by the binding of an essential amino acid, lysine, in the reaction. NEB is a significant reaction leading to end of shelf life in processed proteins; dry milk and whey powders; dry whole eggs; dehydrated meat and fish; frozen meat, fish, and poultry; breakfast cereals; cake mixes; fortified pasta; intermediate-moisture breakfast bars and mixes; and some concentrated juices. In concentrated juices, ascorbic acid (vitamin C) acts as the reducing compound and results in loss of vitamin value as well.

The environmental factors that control NEB are temperature, pH, and a_w. NEB is more sensitive to temperature than is rancidity in dry foods, increasing four to six times in rate for a 10° C increase in temperature. In foods in which both browning and rancidity can occur, at high temperatures NEB predominates, while at low temperatures rancidity predominates. During processing, exposure time at high temperatures should be minimized, since it leads to excessive browning precursors that can shorten shelf life during subsequent storage. Lowering of pH slows browning but is not a desirable method of processing because of the flavor problem of added acid. The major control of browning is through control of the amount of a_w in the food in which the reaction can occur. The lower the water content, the slower the reaction rate for the foods mentioned above. However, very moist foods such as fresh or canned products brown slowly because the reactants are diluted by the high water content and thus there is a_w (0.6 to 0.8) at which point the food undergoes a maximum rate of browning.

With respect to open dating, knowledge of the rate of browning as a function of temperature and water content is very important in order to predict shelf life accurately. How fast a food package gains moisture will also significantly affect shelf life for these types of products.

Other chemical reactions. Other chemical reactions that can lead to food deterioration include the thermal destruction of vitamins such as vitamins A, B_1, and C; the effect of light on pigments such as the browning of meat and bleaching of chlorophyll; the effect of light on riboflavin; the direct oxidation of vitamin C; and the direct oxidation of carotenoid pigments. In every case, the effect of temperature, oxygen level, moisture content, and light must be known to be able to predict the rate of the reaction so that the time to reach the end of shelf life can be measured. Of importance in all these reactions is a decision as to what extent of deterioration is considered to be the end of shelf life. In many cases, this data must be correlated with actual organoleptic and sensory testing of the food so that the correct index of deterioration can be chosen.

Physical Deterioration

Physical damage can also lead to loss of shelf life. The types of physical damage can be classified into various categories, as was chemical deterioration.

Physical bruising/crushing. This mode of deterioration is related to physical abuse of the food in harvest, processing, and distribution. It is most important to fruits and vegetables, since physical abuse leads to microbial attack and decay. Packaging to prevent abuse is a key to long shelf life. With dry materials such as chips, crushing can lead to unacceptability based on consumer desires, This cannot be equated to open dating or loss of shelf life, but proper packaging and care can eliminate this problem.

Wilting. Fresh leafy and tuber vegetables can deteriorate if subjected to low relative humidity. Under these conditions, they lose moisture to the surroundings, resulting in loss of crispness and an increased rate of senescence reactions with subsequent quality and nutrient losses. Proper knowledge of the rate of moisture loss for various packaging materials and the maximum allowable moisture loss can be used as one means of setting open dates of use for fresh produce.

Moisture loss/gain. With some food products such as candy, semimoist pet foods, cakes, and bread, moisture loss leads to an increase in hardening. If a limit of hardness is known to be unacceptable, predictions of the time to reach this level based on equations that describe moisture change with time can be used as one method of predicting end of shelf life. From this, the open date for use can be set. Similarly, one can predict the moisture loss from flour, pasta, and similar dry products for which a natural loss of moisture occurs and a net weight limit is set for sale.

Some products that gain moisture have a textural limit at which they become too soft, such as potato chips, other dried or fried snacks, and crackers. In addition, some crystalline foods such as salt, brown sugar, convenience dry-meal mixes, dry coffee, dry teas, and dried drink mixes will gain enough moisture to become sticky and caked. Predicting shelf life, based on a gain of a critical amount of moisture, is possible if the temperature/relative humidity conditions are known as a function of time and the permeability of a package to moisture is known.

Temperature-induced textural changes. Temperature fluctuations per se can affect physical modes of deterioration. For example, the continuous rise and fall of temperature around a phase-change point leads to melting of fat and the subsequent deterioration of quality of some candies and formulated foods. In frozen foods, repeated thawing and freezing cause loss of tissue moisture and increased chemical reaction rates. If. the temperature fluctuation does not exceed the thawing point, package ice, caused by evaporation of the water from the food into the package space with subsequent freezing as ice crystals, can occur. This results in consumer unacceptability. In addition, if the water loss is significant from a particular surface region, freezer burn—an undesirable discoloration caused by enhanced chemical reaction— can occur. This also is unacceptable to the consumer. Finally, some temperature fluctuations can result in emulsion destabilization of products such as mayonnaise, margarine, salad dressings, and dessert toppings.

Knowledge of the sensitivity of these reactions to the degree of temperature fluctuation and a knowledge of the possible fluctuations occurring in distribution and in the home are needed in order to predict shelf life, In most cases, manufacturers formulate the product to withstand any abuse that may occur. Heating itself can also cause textural changes. In this case, the reaction is usually desirable as in the canning and/or cooking of vegetables, meat, fish, and poultry, Canning at high temperatures is usually undesirable for fruits as they lose their desirable crisp texture and develop a cooked flavor. However, these textural changes are usually not of concern in the storage deterioration of foods.

Staling. Staling is a mode of deterioration important in processed wheat flour products such as bread and cakes. The reaction is basically a crystallization of amylopectin, one of the major starches present in wheat flour. The rate is increased as temperature decreases—opposite to that of the chemical, enzymatic, and microbial reactions discussed earlier, Thus to prevent staling, the food must not be refrigerated. However, not refrigerating the food can lead to other reactions, causing loss of shelf life.

Chemically induced textural changes. As mentioned in the section on chemical deterioration, both lipid oxidation and nonenzymatic browning can result in breakdown of proteins, leading to toughening and an undesirable loss of shelf life. Control and prediction were discussed previously.

BASIC FOOD- PROCESSING PRINCIPLES

The previous section discussed the modes of food deterioration that lead to loss of shelf life and gave examples of prevention. In this section, the basic principles of the major food process methods are listed.

Use of Temperature

Heat preservation. The use of heat to preserve foods is based on the principles of:

- destruction of pathogens,
- destruction of spoilage microbes,
- denaturation of enzymes, and
- softening of tissues to make them more digestible.

Blanching, a food process, is the application of heat under mild conditions, or at high temperature for a short time, to achieve enzyme degradation, drive out oxygen, and soften food tissues. It is used as a preprocess step for canning, freezing, and drying to minimize quality and nutrient losses before the product is preserved.

Pasteurization is a mild heat treatment used to reduce the number of live micro-organisms in food so as to extend shelf life as well as to destroy key pathogens. A pasteurized product is not sterile, however, so some spoilage organisms can grow back and will eventually lead to spoilage. Pasteurization can also be accomplished at high temperature for a short time period, which results in the same reduction of microbes as under mild heat, but with less cooked flavor.

Canning is the process of heat treatment to destroy all organisms of pathogenic nature and most important spoilage organisms. The safety of the process is based on the time needed to reduce the population of *Clostridium botulinum* by a factor of l-million-million at the most heat-resistant point in the food, since this micro-organism is the most heat-resistant and most harmful pathogen. Not all of these types of organisms are killed, however, since some are more heat-resistant than is *Clostridium botulinum* but do not grow under normal canned-food storage conditions. If the food is subjected to high temperature (40° to 50° C), they will grow, causing the food to spoil. Processing to destroy these organisms will destroy the food quality. Because an adequate heat treatment is used, canned "commercially sterile" foods have lost some color: have lost 20 to 30 percent of some vitamins; have a cooked flavor; and have developed a softer texture. Subsequent deterioration is usually confined to chemical modes of decay that do not require oxygen, since the can is hermetically sealed.

Cold preservation. The basis of refrigeration and freezing is that the lower the temperature, the slower the rate of most deteriorative reactions such as senesence, enzymatic decay, chemical decay, and microbial growth. Microbes, in fact, usually cannot grow below - 5° to - 10° C so that freezing stops microbial growth. In some cases, lower temperature increases deterioration because the fracture of membranes releases degradative enzymes, which occurs in chill injury and freezing of some fresh fruits and vegetables. It has been found also that freezing to just below the freezing point of some foods increases deterioration by chemical reactions. This is because not all the water is frozen out and the chemicals are concentrated in the remaining water. Finally, in refrigerated foods, some microbes grow better at lower temperatures, since they can compete better against other spoilage micro-organisms and have a lower optimum growth temperature.

Control of Water Content

Concentration and drying. As water is removed from a food, less is available as a solvent and medium for the deteriorative reactions. Thus, most chemical reactions decrease in rate as the water content decreases. Unfortunately, in the process of removing water, the reactants first begin to concentrate so that the rate of reaction can initially increase. To prevent this, the temperature is kept low during the process, or the water removal is done rapidly enough to get through the danger zone. The degree of drying or concentration is best represented by a factor that describes the a_w in the food.

Figure B-1 depicts a typical moisture absorption isotherm that gives the relationship between moisture content (on a dry basis) and a_w. On a general basis, a significant amount of water must be removed to lower the a_w significantly below 1 (e.g., at 1 g H_2O/g solids or 50- percent water, the a_w. is still very close at 1.0). A_w can also be defined as relative vapor pressure or by ERH as defined in equation 1:

$$a_w = p/p_o = \%\ ERH/100 \tag{1}$$

where

p = the vapor pressure of water in the food

p_o = the vapor pressure of pure water at the same temperature of the food

% ERH = the percent relative humidity in equilibrium with the food at which it neither gains nor loses weight

Of consequence is the fact that for most foods in their natural state the a_w is high, and thus rates of many reactions including microbial growth are also high. In order to preserve the food, the a_w can be lowered by concentrating, drying, or by adding water-binding agents such as sugars and salt. The point on the isotherm of maximum stability is the BET monolayer value (m_o in figure B-1) which is at a low a_w. In general, the rates of most chemical reactions follow the pattern shown in figure B-2—that is, the rate of reaction increases above the monolayer value, reaches a maximum, then decreases again, Rancidity is unusual in that the rate increases again below the monolayer value.

Basically, as a_w is lowered, microbial decay is inhibited first, with bacteria being the most sensitive and molds the most resistant to lowered a_w. Browning, enzymatic activity, lipid oxidation, and nutrient loss also decrease as a_w decreases, with NEB showing a definite maximum rate at an a_w of 0.6 to 0.8.

Concentration is used basically as a preprocess step for foods such as frozen concentrated juices, concentrated canned soups, condensed sweetened milk, and in the preparation of a liquid concentrate that is to be spray-dried, such as for dry milk, dry coffee, dry tea, and some dry food supplements like yeasts. In these latter processes, preconcentration is used because it is a cheaper way to remove water than is drying. However, because of viscosity effects, not all water can be removed, so further drying is required. During concentration, the temperature is usually low, since a vacuum is used. Thus, a cooked flavor and nutrient losses are minimized.

In drying, heat is applied and the relative humidity surrounding the food is lowered so that the water will be evaporated from the food. To achieve both, the air passing over the food is warmed, supplying the energy to remove the water and lowering its humidity. Solid piece materials like vegetables for soup mixes are dried in an air tunnel at 50° to 65° C for 4 to 8 hours. Slurry material like potatoes are dried in thin

Figure B-1 .—Moisture Content v. Water Activity

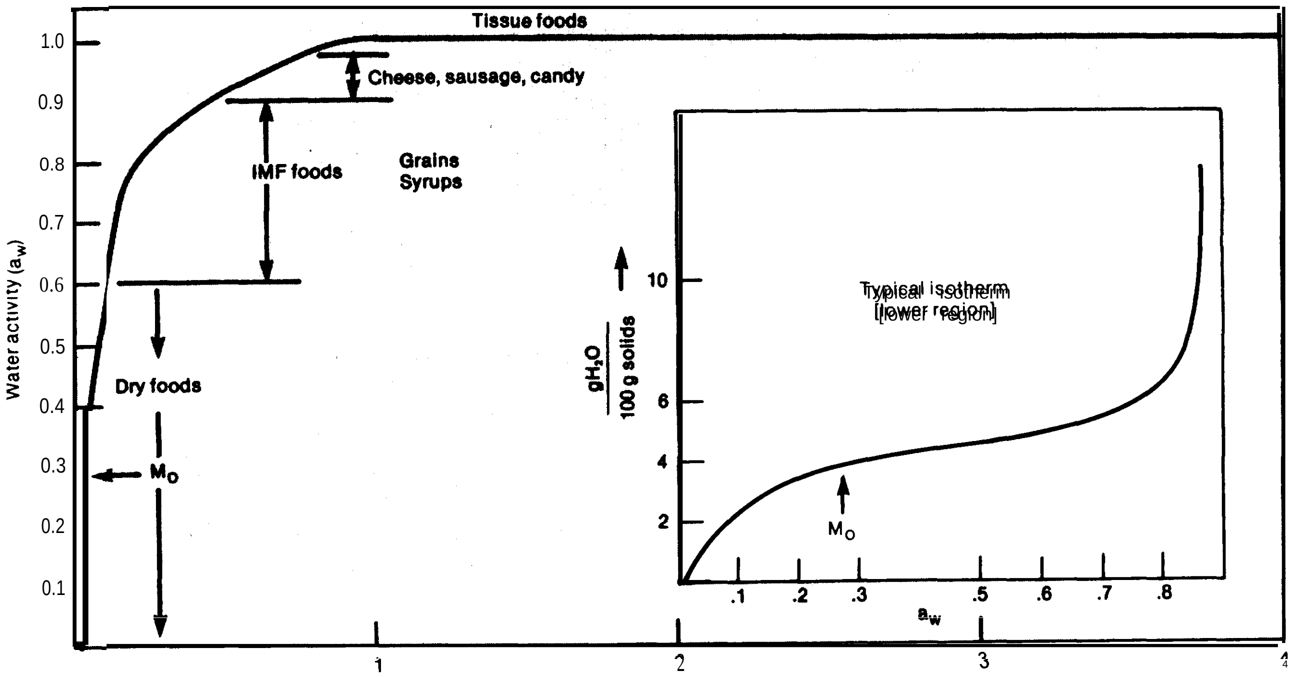
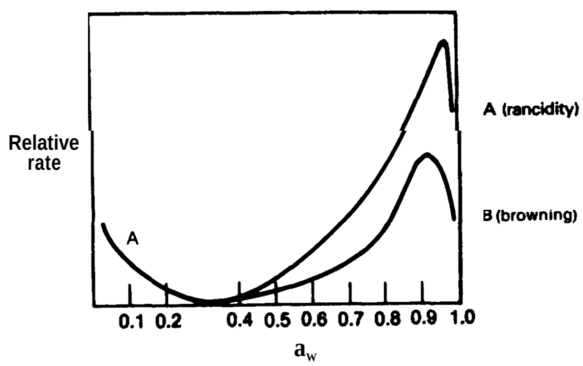


Figure B-2.— Effect of a_w on Rate



layers on hot rotating drums (I ZOO to 1400 C) in 2 to 3 minutes. Although the latter process is at a higher temperature, since it is shorter in time, less quality and nutrient damage takes place. Concentrated liquids can be dried by spraying into a vertical tower through which air at 2o0°to 250° C is passed. In this case, drying occurs in 3 to 20 seconds, so very little damage takes place. Freeze-drying creates the least damage, since it is done at low temperatures in a vacuum. In each case, the principle is to lower the water content and thus the a_w to a level such that during storage, reactions proceed at a very slow rate. The optimum for most foods is at the predicted monolayer value.

It is thus imperative that good packaging be used to prevent the chemical reactions described above, to prevent moisture gain to the point of microbial growth, and to prevent any physical changes caused by moisture gain. If the product contains unsaturated fat, it must also be vacuum packed or nitrogen-flushed to slow the reaction. The rate of oxidation does not drop as much as desired at low oxygen pressure, but the lowering of total oxygen availability limits the overall extent of the reaction. Antioxidants actually have a much better effect on limiting the reaction but may not be able to be incorporated into all dry foods, In some cases like cereals, the antioxidants are lost in the baking process, so they are added into the packaging material.

Humectant use. Rather than removing water by drying, the ability of the water present in foods to act as a medium and solvent can be reduced by adding water-binding agents (humectants) to the food. All dry food solid components have this ability, but the lower the molecular weight, the better the a_w-lowering effect. The common agents used are called humectants. Sugars and salts are such agents, having in fact been used as ancient preservation processes in fermentation, salting, and sugar curing. Addition of sugar or salt in these curing processes is required to lower the a_w to a level below which pathogens and/or spoilage microbes cannot grow, and in the case of fermentation to allow the desirable microbes to grow.

Control of pH by adding acid and growth inhibitors such as antimycotics may be used in conjunction with the humectants where fermentation is undesirable. The result is a shelf-stable food that does not require refrigeration. Common examples are the intermediate-moisture pet foods, confectioneries, some bakery goods, and breakfast tarts. These foods are subject to chemical deterioration because of the high a_w and to moisture loss if left in a dry environment,

Extrusion. Extrusion is a process utilized for many cereal foods, dry snacks, dry animal food, and semimoist pet foods. In this process, a dough is made which is then passed at high pressure by screw action through a cylinder that is heated. The heat causes the components to interact, giving the desired flavor, color, and texture, and as the product releases from the screw, the internal steam in the paste expands and flashes off, This results in further textural changes and drying of the product. In some cases, further air-drying may also be used. Packaging requirements and deterioration mechanisms are similar to that described for dry foods. Of significant importance is moisture gain that can result in a soft, undesirable texture.

Other methods. Deep-fat frying is a drying process in that the hot oil provides the heat to evaporate off the water. In this process, the oil replaces the water in the pores of the food. In baking, the hot air in the oven serves as the drying medium—the longer the baking time, the lower the final moisture of the product. Freezing also can be considered as a drying process; however, the liquid water is converted into a solid that becomes unavailable, It should be noted that for most foods, about 20 to **30** percent of the water is still unfrozen at – 200° C. Therefore, reactions are not stopped by freezing; they are only slowed down due both to lower a_w and low temperature,

Chemical Preservation

Fermentation. Fermentation is one of the oldest of the known food processes. In this method, a desirable organism is allowed to partially convert some of the carbohydrates of the food material into acid, alcohol, and flavor compounds. This can be done naturally by changing the environment, especially the a_w, of the food so that the desired organisms can grow (for example, adding salt to cabbage which inhibits spoilage but allows desirable bacteria to grow). Industrially, a starter culture of the desired organism is usually added to ensure that proper fermentation takes place. The basic principle of the process is to allow the formation of desirable chemicals, such as flavor components and acids or alcohol, the latter of which prevents the growth of undesirable spoilage or pathogenic organisms. The shelf life of fermented foods is limited by the growth of the desired organism. In some cases, further processing is done such as in pasteurizing beer, wine, and vinegar, or the product is kept refrigerated such as in yogurt and cheeses.

Additives. Chemical additives can be used to preserve and/or prolong the shelf life of foods. Each has a specific action by which it operates, The various classes are listed below.

- Acids, such as citric and phosphoric acid. These lower the pH and inhibit undesirable microbes as well as slow undesirable enzymatic and chemical reactions. Acids also contribute to flavor,
- Humectants, such as salt, sugar, and glycerol. These bind the water present, lowering the a_w, and thus reduce the rates of microbial growth, enzymatic activity, and chemical reactions.
- Smoking of foods. This process deposits chemicals from the smoke of burning wood chips onto the surface of foods that inhibit microbial action. The heat also destroys some of the microbes. Because of potential toxicity problems, most manufacturers today use a liquid smoke product from which toxic components have been extracted.
- Metabolic inhibitors, such as calcium propionate and sodium benzoate. These are chemicals that take action against specific types of microbes. They are used where further processing of the food results in undesirable

quality and nutritional changes. Gases can also be used as chemical sterilants and to kill organisms in grain. Ethylene oxide is an example as is chlorine applied in a solution to the surface of fresh meat.

- Anticaking agents, such as the silicates. These are high water-binding agents used in dry-powdered or crystalline foods to prevent caking by selectively binding the water.
- Antioxidant, such as BHA and BHT. These act in the lipid oxidation reaction to slow the rate and thus extend shelf life.
- Chelating agents, such as EDTA and citric acid. These chemicals tie up trace metals to prevent them from catalyzing undesirable reactions such as rancidity.
- Others. Other chemicals such as calcium salts are used to prevent softening of fruits and vegetables during the canning process. Sodium polyphosphates help to hold water in cured and canned meats. Sulfite not only inhibits microbes but slows down enzymatic browning reactions. Some additives are used for mainly esthetic purposes to enhance or restore those flavors or colors lost during normal preservation or for manufacture of engineered foods. Finally, nutrients can be added to restore those lost during preservation.

Separation

Separation processes are used to either create new foods or ingredients, such as making butter out of milk or to transform a raw food into a more digestible or more stable form. Making flour from wheat is an example of the latter. There are many different processes that incorporate in general those methods already discussed above. For example, in the manufacture of instant coffee, the bean is fermented, ground, roasted, leached to form a liquid (the separation step), concentrated, then spray-dried and packaged. The shelf life of the product would depend on the effects of each step.

Gas Atmosphere Control

The shelf life of many fruits and vegetables depends on the rate of respiration after harvest which uses up the stored energy. This rate can be reduced by reducing the oxygen or by increasing CO_2. The methods are generally classified as CA Storage (Controlled Atmospheric Storage) and include:

- reduction and control of O_2 by use of nitrogen,
- hypobaric storage by pulling a vacuum either in a large truck or in a pouch, and
- use of both increased nitrogen and increased CO_2 in the headspace.

CO_2 can also be injected into the headspace of dairy and meat packages to reduce microbial growth and increase shelf life. Vacuum-packaging with CO_2 injection is used to enhance shelf life of poultry products, Overall, shelf life in these cases depends on the degree of maturity after harvest, and temperature and permeability of the package to oxygen and CO_2.

DISTRIBUTION HAZARDS

Once a food is preserved and packaged, it is not stable forever. Each food system slowly decays or deteriorates to the point where it is unacceptable. One goal of open dating could be to give consumers information as to the shelf life of the product so that it is consumed before it is unacceptable. The loss of acceptability, however, may not mean the product is inedible—it only means that the established consumer quality unacceptability standard has been exceeded. The problem is therefore twofold: I) setting a standard for unacceptability and 2) determining or predicting the loss that occurs from point of distribution to point of consumption.

Data on actual shelf-life modes and shelf life of various products based on some endpoint standards have been collected and are in the main data base part of this study. Appendix C discusses the second problem—that is, based on environmental factors, how can one predict changes in shelf life. The important environmental influences include:

- temperature—increasing, decreasing, fluctuating:
- moisture (relative humidity)—gain, loss;
- oxygen level; and
- light.