5 General Principles of Food Preservation: Asepsis, Removal, Anaerobic Conditions

Foods for human consumption can be divided into eight main groups, four of plant and four of animal origin, and several lesser groups. The eight main classes of foods are as follows:

Foods from plants	*Foods from animals*
Cereals and cereal products	Meats and meat products
Sugar and sugar products	Poultry and eggs
Vegetables and vegetable products	Fish and other seafood
Fruits and fruit products	Milk and milk products

To the list of foods of plant origin could be added spices and other flavoring materials, nutmeats, and fungi grown for food (yeasts, molds, mushrooms, etc.). Sodium chloride is a mineral food, a flavoring material, an essential nutrient, and a chemical preservative. Some foods may be fortified with minerals, e.g., iron and calcium compounds added to flour. Some of the coloring and flavoring materials used in foods are synthetic. Vitamins usually are present in foods but may be added or consumed separately after chemical synthesis or production by microorganisms.

Most kinds of food are readily decomposed by microorganisms unless special methods are used for their preservation.

METHODS OF FOOD PRESERVATION

The chief methods of food preservation are as follows:

1. Asepsis, or keeping out microorganisms.
2. Removal of microorganisms.
3. Maintenance of anaerobic conditions, e.g., in a sealed, evacuated container.
4. Use of high temperatures.
5. Use of low temperatures.
6. Drying; this includes the tying up of water by solutes, hydrophilic colloids, etc.
7. Use of chemical preservatives, either developed by microorganisms or added.
8. Irradiation.
9. Mechanical destruction of microorganisms, e.g., by grinding, high pressures, etc. (not used industrially).
10. Combinations of two or more of the above methods. Only rarely is a single method effective, and usually several are combined. For example, canned foods are preserved by heat-processing them in an evacuated, sealed can. When preservative methods are combined, the required intensity of each usually is reduced

to less than that for preservation by one agency alone. When benzoate or sorbate is added to fruit juices, less heat is required for sterilization of these products. If salt, sugar, and vinegar are all added to catsup, pickles, or relishes, each can be used at a lower concentration than if only one were added. Foods previously irradiated with gamma rays or treated with antibiotic tylosin require less heat for their sterilization than foods not so treated. Numerous other examples will be found in subsequent chapters.

PRINCIPLES OF FOOD PRESERVATION

In accomplishing the preservation of foods by the various methods, the following principles are involved:

1. Prevention or delay of microbial decomposition
   - **a** By keeping out microorganisms (asepsis)
   - **b** By removal of microorganisms, e.g., by filtration
   - **c** By hindering the growth and activity of microorganisms, e.g., by low temperatures, drying, anaerobic conditions, or chemicals
   - **d** By killing the microorganisms, e.g., by heat or radiation
2. Prevention or delay of self-decomposition of the food
   - **a** By destruction or inactivation of food enzymes, e.g., by blanching
   - **b** By prevention or delay of purely chemical reactions, e.g., prevention of oxidation by means of an antioxidant
3. Prevention of damage because of insects, animals, mechanical causes, etc., a subject beyond the scope of this text

The methods used to control the activities of microorganisms usually are effective against enzymatic activity in the food or chemical reactions. Methods such as drying and the use of low temperatures, however, permit autodecomposition to continue unless special precautions are taken. For example, most vegetables are balanced (heated) to inactivate their enzymes before being frozen.

Delay of Microbial Decomposition

Many common methods of food preservation depend not on the destruction or removal of microorganisms but on delay in the initiation of growth and hindrance to growth once it has begun.

A summary of the major preservation factors and their mode of action and achievement is presented in Table 5.1.

Growth Curve of Microbial Cultures Whenever microorganisms are added to a food and conditions are favorable, the organisms will begin to multiply and will pass through a succession of phases. When counts of organisms are made periodically and the results are plotted with logarithms of numbers of organisms per milliliter as ordinates and time units as abscissas, a **growth curve** is obtained, as shown in Figure 5.1. This curve ordinarily is divided into phases as indicated in the figure: (1) the initial **lag phase** (*A* to *B*), during which there is no growth or even a decline in numbers, (2) the phase of **positive acceleration** (*B* to *C*), during which

Table 5.1 *Classification of Preservation Factors*

Mode of action	Preservation factor	Mode of achievement
Inactivation of microorganisms	Heat	Pasteurization Sterilization
	Radiation	Radicidation Radurization Radappertization
Inhibition or slowing of growth of microorganisms	Cool	Chill Freeze
	Restrict water (reduce water activity)	Dry Add salt Add sugar Add glycerol Add other solutes or use combinations of the above
	Restrict oxygen	Vacuum pack Nitrogen pack
	Increase carbon dioxide	CO_2 pack
	Acidity	Add acids Lactic fermentation Acetic fermentation
	Alcohol	Fermentation Fortification
	Add preservatives	Inorganic (e.g., sulphite, nitrite Organic (e.g., sorbate, benzoate, parabens, etc.) Antibiotics (e.g., nisin) Smoke
Restriction of access of microorganisms to product	Microstructure control	Emulsion (w/o)
	Decontamination	Ingredients Packaging materials, e.g., by chemicals (HCl, H_2O_2) heat, irradiation (ionizing or X; nonionizing)
	Aseptic or clean handling	Superclean processing Aseptic processing
	Packaging	Aseptic or clean packaging

Source: Could et al.(1983).

the rate of growth is continuously increasing, (3) the **logarithmic** or **exponential phase** of growth (*C* to *D*), during which the rate of multiplication is most rapid and is constant, (4) the phase of **negative acceleration** (*D* to *E*), during which the rate of multiplication is decreasing, (5) the **maximal stationary phase** (*E* to *F*), where numbers remain constant, (6) the **accelerated death phase** (*F* to *G*), (7) the **death phase or phase of decline** (*G* to *H*), during which numbers decrease at a faster rate than new cells are formed, and (8) the **survival phase** (*H* to *I*), during which no cell division occurs but remaining cells survive on endogenous nutrients. With many

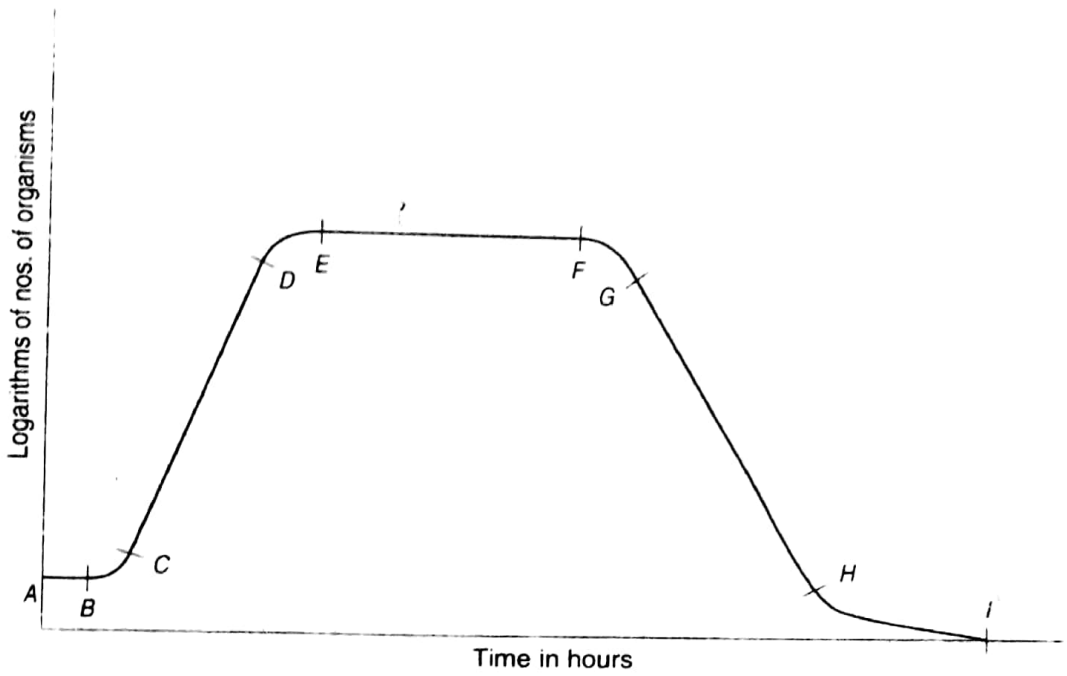

Fig. 5.1 *Growth curve.* A *to* B, *lag phase;* B *to* C, *phase of positive acceleration;* C *to* D, *logarithmic or exponential phase;* D *to* E, *phase of negative acceleration;* E *to* F, *maximal stationary;* F *to* G, *accelerated death phase;* G *to* H, *death phase; and* H *to* I, *survival phase.*

bacteria (or other microorganisms) the numbers do not decrease at a fixed rate to zero, as indicated by the unbroken line in the figure, but taper off very gradually as low numbers are approached, as shown by the broken line, and a few viable cells remain for some time.

Applications to Food Preservation Especially important in food preservation (i.e., prevention of spoilage) is the lengthening, as much as possible, of the lag phase and the phase of positive acceleration. This can be accomplished in different ways:

1. **By introducing as few spoilage organisms as possible**, i.e., by reducing the amount of contamination; the fewer organisms present, the longer the lag phase.
2. **By avoiding the addition of actively growing organisms** (from the logarithmic phase of growth). Such organisms might be growing on unclean containers, equipment, or utensils that come in contact with foods.
3. **By one or more unfavorable environmental conditions:** unfavorable foods, moisture, temperature, pH, or O-R potential, or presence of inhibitors. The more unfavorable the conditions, the longer the delay of the initiation of growth.
4. **By actual damage to organisms by processing methods such as heating or irradiation.** Thus, for example, bacteria or their spores subjected to sublethal heat treatments have been found to require a better culture medium for growth than do the unheated organisms. Often a combination of methods for delaying the initiation of growth is enough to give a food the desired storage life.

From the growth curve, the generation time of the organisms, i.e., the time that elapses between the formation of a daughter cell and its division into two new cells, can be calculated. The generation time will be shortest during the logarithmic phase of growth, and its length will vary with the environmental conditions during growth,

e.g., the type of food, its pH, temperature, O-R potential, available moisture, and presence of inhibitors. The generation time shortens as conditions become more favorable and lengthens as they become less favorable. Any change in the environment that will extend the generation time will more than proportionally lengthen the keeping time of the food. A drop in temperature, for example, will lengthen the generation time and hence the keeping time. If we start with a single cell, and if it divides every 30 min, there will be about I million cells in 10 hr but only about 1,000 cells if the generation time is 60 min and only 32 cells if it is 120 min. This emphasizes the importance of avoiding contamination of food with microorganisms that are in the logarithmic phase of growth, for when their generation time is the shortest, the lag phase will be brief or nonexistent and multiplication will proceed at its most rapid rate.

Prevention of Microbial Decomposition

Microbial decomposition of foods will be prevented if all spoilage organisms are killed (or removed) and recontamination is prevented. Merely stopping the multiplication of microorganisms, however, does not necessarily prevent decomposition, for viable organisms or their enzymes may continue to be active. As will be pointed out in later chapters, killing microorganisms by most agencies is easier when smaller initial numbers are present that with larger numbers; this reemphasizes the importance of contamination. Especially important is the introduction or building up of microorganisms resistant to the lethal agent being employed, for example, heat-resistant bacterial spores when foods are to be heat-processed. Vegetative cells of organisms in their logarithmic phase of growth are least resistant to lethal agencies, and they are more resistant in their late lag or maximal stationary phase of growth.

ASEPSIS

In nature there are numerous examples of asepsis, or keeping out microorganisms, as a preservative factor. The inner tissues of healthy plants and animals usually are free from microorganisms, and if any microorganisms are present, they are unlikely to initiate spoilage. If there is a protective covering about the food, microbial decomposition is delayed or prevented. Examples of such coverings are the shells of nuts, the skins of fruits and vegetables, the husks of ear corn, the shells of eggs, and the skin, membranes, or fat on meat or fish. It is only when the protective covering has been damaged or decomposition has spread from the outer surface that the inner tissues are subject to decomposition by microorganisms.

In the food industries an increasing amount of attention is being given to the prevention of the contamination of foods, from the raw material to the finished product. The food technologist is concerned with the "bioburden" of microorganisms on or in a food and considers both kinds and numbers of organisms present. The *kinds* are important in that they may include spoilage organisms, those desirable in a food fermentation, or even pathogenic microorganisms. The *numbers* of microorganisms are important because the more spoilage organisms there are, the more likely food spoilage will be, the more difficult will be the preservation of food, and the more likely will be the presence of pathogens. The bioburden may be the

result of contamination, growth of organisms, or both. The quality of many kinds of foods is judged partly by the numbers of microorganisms present. Following are some examples of the importance of aseptic methods in food industries.

Packaging of foods is a widely used application of asepsis. The covering may range from a loose carton or wrapping, which prevents primarily contamination during handling, to the hermetically sealed container of canned foods, which, if tight, protects the processed contents from contamination by microorganisms.

In the dairy industry, contamination with microorganisms is avoided as much as is practicable in the production and handling of market milk and milk for other purposes, and the quality of the milk is judged by its bacterial content.

In the canning industry the bioburden, or load, of microorganisms determines the heat process necessary for the preservation of a food, especially if the contamination introduces heat-resistant spoilage organisms, such as spore-forming thermophiles that may come from equipment; and the sealed can prevents recontamination after the heat treatment.

In the meat-packing industry sanitary methods of slaughter, handling, and processing reduce the load and thus improve the keeping quality of the meat or meat products.

In industries involving controlled food fermentation e.g., in cheese making, the fewer the competing organisms in the fermenting material, the more likely the success of the fermentation.

REMOVAL OF MICROORGANISMS

For the most part the removal of microorganisms is not very effective in food preservation, but under special conditions it may be helpful. Removal may be accomplished by means of filtration, centrifugation (sedimentation or clarification), washing, or trimming.

Filtration is the only successful method for the complete removal of organisms, and its use is limited to clear liquids. The liquid is filtered through a previously sterilized "bacteriaproof" filter made of sintered glass, diatomaceous earth, unglazed porcelain, membrane pads, or similar material, and the liquid is forced through by positive or negative pressure. This method has been used successfully with fruit juices, beer, soft drinks, wine, and water.

Centrifugation, or sedimentation, generally is not very effective, in that some but not all of the microorganisms are removed. Sedimentation is used in the treatment of drinking water but is insufficient by itself. When centrifugation (clarification) is applied to milk, the main purpose is not to remove bacteria but to take out other suspended materials, although centrifugation at high speeds removes most of the spores.

Washing raw foods can be helpful in their preservation but may be harmful under some conditions. Washing cabbage heads or cucumbers before their fermentation into sauerkraut and pickles, respectively, removes most of the soil microorganisms on the surface and in this way increases the proportion of desirable lactic acid bacteria in the total flora. Washing fresh fruits and vegetables removes soil organisms that may be resistant to the heat process during the canning of these foods. Obviously

the removal of organisms and of food for them from equipment coming into contact with foods, followed by a germicidal treatment of the apparatus, is an essential and effective procedure during the handling of all kinds of foods. Washing foods may be dangerous if the water adds spoilage organisms or increases the moisture so that growth of spoilage organisms is encouraged.

Trimming away spoiled portions of a food or discarding spoiled samples is important from the standpoint of food laws and may be helpful in food preservation. Although large numbers of spoilage organisms are removed in this way, heavy contamination of the remaining food may take place. Trimming the outer leaves of cabbage heads is recommended for the manufacture of sauerkraut.

MAINTENANCE OF ANAEROBIC CONDITIONS

A preservative factor in sealed, packaged foods may be the anaerobic conditions in the container. A complete fill, evacuation of the unfilled space (the head space in a can), or replacement of the air by carbon dioxide or by an inert gas such as nitrogen will bring about anaerobic conditions. Spores of some of the aerobic sporeformers are especially resistant to heat and may survive in canned food but be unable to germinate or grow in the absence of oxygen. Production of carbon dioxide during fermentation and accumulation at the surface will serve to make conditions anaerobic there and prevent the growth of aerobes.

6 Preservation by Use of High Temperatures

The killing of microorganisms by heat is supposed to be caused by the denaturation of the proteins and especially by the inactivation of enzymes required for metabolism. The heat treatment necessary to kill organisms or their spores varies with the kind of organism, its state, and the environment during heating. Depending on the heat treatment employed, only some of the vegetative cells, most or all of the cells, part of the bacterial spores, or all of them may be killed. The heat treatment selected will depend on the kinds of organisms to be killed, other preservative methods to be employed, and the effect of heat on the food.

FACTORS AFFECTING HEAT RESISTANCE (THERMAL DEATH TIME)

Cells and spores of microorganisms differ widely in their resistance to high temperatures. Some of these differences are the result of factors that can be controlled, but others are characteristic of the organisms and cannot always be explained. There are differences in heat resistance within a population of cells or spores, as illustrated by the frequency distribution curve in Figure 6.1. A small number of cells have low resistance (points *A* to *B*); most of the cells have a medium resistance (points *B* to *C*); and a small number have high resistance (points *C* to *D*). Conditions of growth may favor one or the other of these groups, and, by selection, cultures that are more or less heat-resistant than usual can be produced.

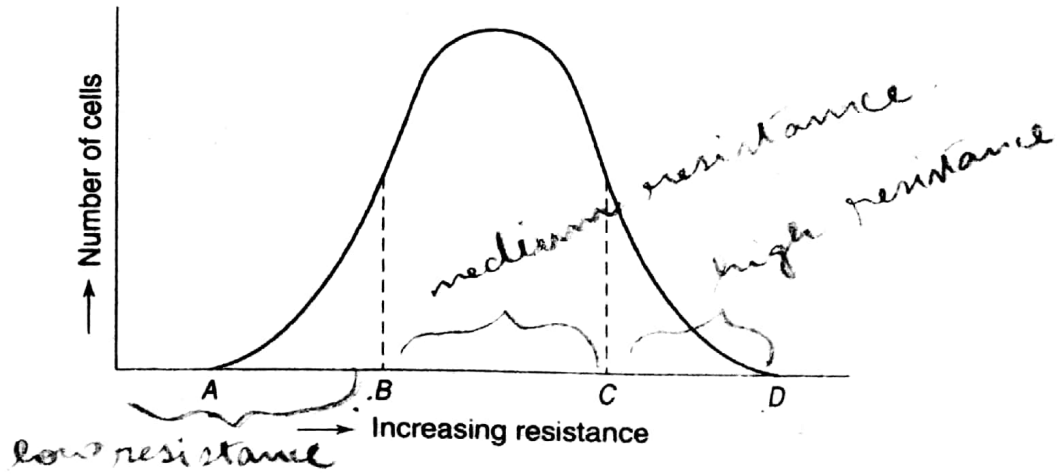

Fig. 6.1 *Frequency distribution curve showing heat resistance in a culture.*

Certain factors are known to affect the heat resistance of cells or spores and must be kept in mind when microorganisms are compared and when heat treatments for the destruction of an organism are considered. The chief known factors are as follows:

1. **The temperature-time relationship.** The time for killing cells or spores under a given set of conditions decreases as the temperature is increased. This is illustrated in Table 6.1 by the results of Bigelow and Esty (1920) with 115,000 spores of flat sour bacteria per milliliter in corn juice at pH 6.1

2. **Initial concentration of spores (or cells).** The more spores or cells present, the greater the heat treatment necessary to kill all of them. Bigelow and Esty heated spores of a thermophile from spoiled canned food in corn juice at pH 6.0 at 120 C, with the results shown in Table 6.2.

3. **Previous history of the vegetative cells or spores.** The conditions under which the cells have been grown and spores have been produced and their treatment thereafter will influence their resistance to heat.

Table 6.1 *Effect of Temperature of Heating on Time Needed to Kill Spores of Flat Sour Bacteria*

Temperature, C	Thermal death time, or time to destroy all spores, min
100	1,200
105	600
110	190
115	70
120	19
125	7
130	3
135	1

Source: Bigelow and Esty (1920).

Table 6.2 *Effect of Initial Numbers of Spores on Time Required to Kill them*

Initial concentration of spores, number/ml	Thermal death time, or time required to kill all spores, min at 120 C
50,000	14
5,000	10
500	9
50	8

Source: Bigelow and Esty (1920).

a. **Culture medium.** The medium in which growth takes place is especially important. The effect of the nutrients in the medium, their kind, and the amount vary with the organism, but in general the better the medium for growth, the more resistant the cells or spores. The presence of an adequate supply of accessory growth factors usually favors the production of heat-resistant cells or spores. This probably is why vegetable infusions and liver extract increase heat resistance.

According to Curran (1935), spores formed and aged in soil or oats are more resistant than those in broth or agar. Carbohydrates, amino acids, and organic acid radicals have an effect, but it is difficult to predict. A small amount of glucose in a medium may lead to increased heat resistance, but more sugar may result in the formation of enough acid to cause decreased heat resistance. Some salts seem to have an effect; phosphate and magnesium ions, for instance, are said to decrease the heat resistance of bacterial spores produced in a medium containing them. Prolonged exposure to metabolic products reduces the heat resistance of cells and spores.

b. Temperature of incubation. The temperature of growth of cells and the temperature of sporulation influences their heat resistance. In general, resistance increases as the incubation temperature is raised toward the optimum for the organism and for many organisms increases further as the temperature approaches the maximum for growth. *Escherichia coli*, for example, is considerably more heat-resistant when grown at 38.5 C, which is near its optimal temperature, than at 28 C. Spores of *Bacillus subtilis*, grown at different temperatures in 1 percent peptone water, were heated with the results shown in Table 6.3.

Table 6.3 *Effect of Temperature of Formation of Spores of Bacillus Subtilis on their Heat Resistance*

Temperature of incubation, C	*Time to kill at 100 C, min*
21 – 23	11
37 (optimum)	16
41	18

Source: Williams (1929).

c. Phase of growth or age. The heat resistance of vegetative cells varies with the stage of growth and of spores with their age. Bacterial cells show their greatest resistance during the late lag phase but almost as great resistance during their maximum stationary phase, followed by a decline in resistance (see Chapter 5). The cells are least resistant during their phase of logarithmic growth. Very young (immature) spores are less resistant than are mature ones. Some spores increase in resistance during the first weeks of storage but later begin to decrease in resistance.

d. Desiccation. Dried spores of some bacteria are harder to kill by heat than are those kept moist, but this apparently does not hold for all bacterial spores.

4. Composition of the substrate in which cells or spores are heated. The material in which the spores or cells are heated is so important that it must be stated if a thermal death times is to have meaning.

a. Moisture. Moist heat is a much more effective killing agent than dry heat, and as a corollary dry materials require more heat for sterilization than moist ones. In the bacteriological laboratory about 15 to 30 min at 121 C in the moist heat of an autoclave will effect sterilization of ordinary materials, but 3 to 4 hr at 160 to 180 C is necessary when the dry heat of an oven is employed. Spores of *Bacillus*

subtilis are killed in less than 10 min in steam at 120 C, but in anhydrous glycerol 170 C for 30 min is required.

b. Hydrogen-ion concentration (pH). In general, cells or spores are most heat resistant in a substrate that is at or near neutrality. An increase in acidity or alkalinity hastens killing by heat, but a change toward the acid side is more effective than a corresponding increase in alkalinity. Spores of *B. subtilis* heated at 100 C in 1:15 *m* phosphate solutions, adjusted to various pH values, gave the results shown in Table 6.4. Other examples will be given in the discussion of the heat processing of canned foods.

Table 6.4 *Effect of pH on Heat Resistance of Spores of* Bacillius Subtilis

pH	Time to survival, min
4.4	2
5.6	7
6.8	11
7.6	11
8.4	9

Source: Williams (1929).

Cameron (1940) divided canned foods into the **acid food**, the pH values of which are below 4.5, and the **low-acid foods,** with a pH above 4.5. Acid foods include the common fruits and certain vegetable products, and the low-acid foods are those such as meat, seafood, milk, and most of the common vegetables. A further subdivision was suggested by Cameron (1940).

(1) *Low-acid foods,* with a pH above 5.3, including such foods as peas, corn, lima beans, meats, fish, poultry, and milk (although Cameron included only vegetables and fruits in his original grouping).

(2) *Medium-acid foods,* with a pH between 5.3 and 4.5, including such foods as spinach, asparagus, beets, and pumpkin.

(3) *Acid foods,* with a pH between 4.5 and 3.7, including such foods as tomatoes, pears, and pineapple.

(4) *High-acid foods,* with a pH of 3.7 and below, including such foods as berries and sauerkraut.

The effect of the pH of the substrate is complicated by the fact that heating at high temperature causes a decrease in the pH of low- or medium-acid foods; and the higher the original pH, the greater the drop in pH caused by heating. Foods with an original pH of less than 5.5 to 5.8 change little in acidity as a result of heating.

c. Other constituents of the substrate. The only salt present in appreciable amounts in most foods is sodium chloride, which in low concentrations has a protective effect on some spores.

Sugar seems to protect some organisms or spores but not others. The optimal concentration for protection varies with the organism: it is high for some osmophilic

Table 6.5 *Effect of protective substances on heat resistance of bacteria*

	Temperature, C		
Substance	***S. lactis***	***E. coli***	***L. bulgaricus***
Cream	69–71	73	95
Whole milk	63–65	69	91
Skim milk	59–63	65	89
Whey	57–61	63	83
Broth	55–57	61	

It will be observed that as the content of protective substances (proteins and fat) decreased in the media, the temperature needed to kill the organism in 10 minutes decreased.

Source: Brown and Peiser (1916).

organisms and low for others, high for spores and low for non osmophilic cells. The protective effect of sugar may be related to a resulting decrease in a_w. A reduced a_w does result in an increase in observed heat resistance.

Solutes differ in their effect on bacteria. Glucose, for example, protects *Escherichia coli* and *Pseudomonas fluorescens* against heat better than sodium chloride at a_w levels near the minimum for growth. On the other hand, glucose affords practically no protection or is even harmful to *Staphylococcus aureus*, whereas sodium chloride is very protective.

Since the concentration of solutes may affect the heat process necessary for sterilization, canners sometimes further classify foods as high-soluble-solids foods, such as sirups and concentrates, and low-soluble-solids foods, such as fruits, vegetables, and meats.

Colloidal materials, especially proteins and fats, are protective against heat. This is well illustrated in Table 6.5 by the data of Brown and Peiser (1916) who used *thermal death points*.

Antiseptic or germicidal substances in the substrate aid heat in the destruction of organisms. Thus hydrogen peroxide plus heat is used to reduce the bacterial content of sugar and is the basis of a process for milk.

HEAT RESISTANCE OF MICROORGANISMS AND THEIR SPORES

The heat resistance of microorganisms usually is expressed in terms of their **thermal death time,** which is defined as the time it takes at a certain temperature to kill a stated number of organisms (or spores) under specified conditions. This sometimes is referred to as the **absolute thermal death time** to distinguish it from the **majority thermal death time** for killing most of the cells or spores present and the **thermal death rate,** expressed as the rate of killing. **Thermal death point,** now used little, is the temperature necessary to kill all the organisms in 10 min.

The reports of different workers on the comparative heat resistance of various kinds of yeasts, molds, and bacteria and their spores do not entirely agree because of

differences between the cultures used and the conditions during heating. Therefore, only generalizations will be made, with the results of some workers cited as examples.

❑ Heat Resistance of Yeasts and Yeast Spores

The resistance of yeasts and their spores to moist heat varies with the species and even the strain and, of course, with the substrate in which they are heated. In general the ascospores of yeasts need only 5 to 10 C more heat for their destruction than the vegetative cells from which they are formed. Most ascospores are killed by 60 C for 10 to 15 min; a few are more resistant, but none can survive even a brief heating at 100 C. Vegetative yeasts usually are killed by 50 to 58 C for 10 to 15 min. Both yeasts and their spores are killed by the pasteurization treatments given milk (62.8 C for 30 min or 71.7 C for 15 sec), and yeasts are readily killed in the baking of bread, where the temperature of the interior reaches about 97 C.

❑ Heat Resistance of Molds and Mold Spores

Most molds and their spores are killed by moist heat at 60 C in 5 to 10 min, but some species are considerably more heat-resistant. The asexual spores are more resistant than ordinary mycelium and require a temperature 5 to 10 C higher for their destruction in a given time. Many species of *Aspergillus* and some of *Penicillium* and *Mucor* are more resistant to heat than are other molds; a very heat resistant mold on fruits is *Byssochlamys fulva* (Paecillomyces), with resistant ascospores. The pasteurizing treatments given milk usually kill all molds and their spores, although spores of some aspergilli, not commonly found in milk, could survive such a heat process.

Sclerotia are especially difficult to kill by heat. Some can survive a heat treatment of 90 to 100 C for a brief period and have been known to cause spoilage in canned fruits. It was found that 1,000 min at 82.2 C or 300 min at 85 C was necessary to destroy sclerotia from a species of *Penicillium*.

Mold spores are fairly resistant to dry heat. Data from various workers indicate that dry heat at 120 C for as long as 30 min will not kill some of the more resistant spores.

❑ Heat Resistance of Bacteria and Bacterial Spores

The heat resistance of vegetative cells of bacteria varies widely with the species, from some of the delicate pathogens that are easily killed to thermophiles that may require several minutes at 80 to 90 C. A few general statements can be made about the heat resistance of vegetative cells of bacteria: (1) cocci usually are more resistant than rods, although there are many notable exceptions; (2) the higher the optimal and maximal temperatures for growth, the greater the resistance to heat is likely to be; (3) bacteria that clump considerably or form capsules are more difficult to kill than those which do not; (4) cells high in lipid content are harder to kill than are other cells.

A few examples of thermal death times of bacterial cells are shown in Table 6.6.

It should be kept in mind that these thermal death times (and those to be given later for spores) are for various concentrations of cells (or spores), heated in different substrates, and might be higher or lower under other conditions.

Table 6.6 *Thermal Death Times of Bacterial Cells*

Bacterium	Time, min	Temperature, C
Neisseria gonorrhoeae	2–3	50
Salmonella typhi	4.3	60
Staphylococcus aureus	18.8	60
Escherichia coli	20–30	57.3
Streptococcus thermophilus	15	70–75
*Lactobacillus bulgaricus**	30	71

The heat resistance of bacterial spores varies greatly with the species of bacterium and the conditions during sporulation. Resistance at 100 C may vary from less that 1 min to over 20 hr. In general, spores from bacteria with high optimal and maximal temperatures for growth are more heat-resistant than those from bacteria growing best at lower temperatures. Or a sporeformer growing with another of higher heat resistance may have increased resistance, e.g., *Clostridium perfringens growing with C. sporogenes*. Examples of thermal death times of bacterial spores are given in Table 6.7.

Table 6.7 *Thermal Death Times of Bacterial Spores*

Spores of	Time to kill at 100 C, min
Bacillus anthracis	1.7
Bacillus subtilis	15–20
Clostridium botulinum	100–330
*Clostridium calidotolerans**	520
Flat sour bacteria	Over 1.030

❑ Heat Resistance of Enzymes

Although most food and microbial enzymes are destroyed at 79.4 C, some may withstand higher temperatures, especially if high-temperature-short-time heating is employed.

One of the goals of a thermal process (Witter, 1983) is to inactivate enzymes that can cause product deterioration during storage. Generally, thermal processes designed to inactivate microorganisms will also inactivate enzymes of concern. There are, however, notable exceptions. For example, some hydrolases (proteinases and lipases) will retain a substantial level of activity after an ultrahigh-temperature process. The residual activity of these enzymes may spoil the processed product during long-term storage. Another enzyme, bovine phosphatase, is actually used as a "monitor" in the pasteurization of milk. Detection of the bovine enzyme in processed milk usually indicates that the milk was not properly pasteurized. False positives are possible if high levels of microbial phosphatase are present.

a known concentration of spores of the resistant spoilage organism. These cans and uninoculated controls are processed for several time intervals near that calculated for the temperature chosen, are incubated to test for spoilage, and are subcultured to test for sterility. Usually a margin of safety is allowed beyond the minimal treatment for killing the spores being tested when recommendations are made concerning a thermal process time. It should be kept in mind that the processes recommended will be successful only for the concentration of spores used and might not take care of gross contamination beyond that level.

HEAT TREATMENTS EMPLOYED IN PROCESSING FOODS

The temperature and time used in heat-processing a food will depend on what effect heat has on the food and what other preservative methods are to be employed. Some foods, such as milk and peas, can be heated to only a limited extent without undesirable changes in appearance or loss in palatability, whereas others, like corn or pumpkin, can undergo a more rigorous heat treatment without marked change. The greater the heat treatment, the more organisms will be killed, up to the heating that will produce sterility of the product. If not all the organisms are killed, either the heating must destroy all potential spoilage organisms or the food must be handled thereafter so as to delay or prevent the growth of surviving spoilage organisms. In canning, an attempt is made to kill all organisms that could spoil the food during later handling; in pasteurization, most of the spoilage organisms are killed but others survive and must be inhibited by low temperatures or some other preservative method if spoilage is to be prevented. The various degrees of heating used on foods might be classified as (1) pasteurization, (2) heating at about 100 C, and (3) heating above 100 C.

❑ Pasteurization

Pasteurization is a heat treatment that kills part but not all of the microorganisms present and usually involves the application of temperatures below 100 C. The heating may be by means of steam, hot water, dry heat, or electric currents, and the products are cooled promptly after the heat treatment. Pasteurization is used (1) when more rigorous heat treatments might harm the quality of the product, as with market milk, (2) when one aim is to kill pathogens, as with market milk, (3) when the main spoilage organisms are not very heat resistant, such as the yeasts in fruit juices, (4) when any surviving spoilage organisms will be taken care of by additional preservative methods to be employed, as in the chilling of market milk, and (5) when competing organisms are to be killed, allowing a desired fermentation, usually by added starter organisms, as in cheese making.

Preservative methods used to supplement pasteurization include (1) refrigeration e.g., of milk, (2) keeping out microorganisms, usually by packaging the product in a sealed container, (3) maintenance of anaerobic conditions, as in evacuated, sealed containers, (4) addition of high concentrations of sugar, as in sweetened condensed milk, and (5) presence or addition of chemical preservatives, e.g., the organic acids on pickles.

Times and temperatures used in the pasteurizing process depend on the method employed and the product treated. The high-temperature-short-time (HTST) method employs a comparatively high temperature for a short time, whereas the low-temperature-long-time, or holding (LTH), method uses a lower temperature for a longer time. Some examples follow of pasteurizing treatments given various types of foods. The minimal heat treatment of market milk is at 62.8 C for 30 min in the holding method; at 71.7 C for at least 15 sec in the HTST method; and at 137.8 C for at least 2 sec in the ultrapasteurized method. One basis for the selection of this treatment is the thermal resistance of the rickettsia responsible for Q fever, *Coxiella burnetti*, an organism that may be transmitted by milk. The heat treatment often is greater when milk is to be used for other purposes, but it sometimes is slighted in cheese making, in which event the cheese should be aged, as is raw-milk cheese. Ice cream mix is pasteurized at various temperatures for different times, usually receiving a greater heat treatment than market milk. For example, ice cream mix may be heated at 71.1 C for 30 min or at 82.2 C for 16 to 20 sec. Grape wines may be pasteurized for 1 min at 82 to 85 C in bulk, whereas fruit wines sometimes are heated to 62.8 C or over and bottled hot. Beer may be pasteurized at 60 C or above, the time varying with the temperature. Dried fruits usually are pasteurized in the package at 65.6 to 85 C for 30 to 90 min, the treatment varying with the kind of fruit and the size of the package. The pasteurizing treatment given fruit juices depends on their acidity and whether they are in bulk or in the bottle or can. Recommended for bottled grape juice is 76.7 C for 30 min or flash treatment in bulk at 80 to 85 C, and for apple juice 60 C if bottled and 85 to 87.8 C for 30 to 60 sec in bulk. The average heat treatment for carbonated juices would be 65.6 C for 30 min. When vinegar is pasteurized in the bottle in a water bath, all the vinegar is brought to at least 65.6 C. If flash-pasteurized, the vinegar is heated so as to be at 65.6 to 71.1 C when the bottle is closed. When pasteurized in bulk, the vinegar is held at 60 to 65.6 C for 30 min.

❑ Heating at about 100 C

Formerly, home canners processed all foods for varying lengths of time at 100 C or less. This treatment was sufficient to kill everything but bacterial spores in the food and often was sufficient to preserve even low- and medium-acid foods. Now, however, most home canners use pressure cookers for the less acid foods. Many acid foods can be processed successfully at 100 C or less, for example, sauerkraut and highly acid fruits. A temperature of approximately 100 C is obtained by boiling a liquid food, by immersion of the container of food in boiling water, or by exposure to flowing steam. Some very acid foods, e.g., sauerkraut, may be preheated to a temperature somewhat below 100 C, packaged hot, and not further heat-processed. Blanching fresh vegetables before freezing or drying involves heating briefly at about 100 C.

During **baking,** the internal temperature of bread, cake, or other bakery products approaches but never reaches 100 C as long as moisture is present, although the oven is much hotter. The temperature of unsealed canned goods heated in the oven cannot exceed the boiling temperature of the liquid present. As will be indicated subsequently, bacterial spores that survive the baking of bread (maximal temperature about 97 C) may cause ropiness. **Simmering** is incipient or gentle boiling, with the temperature about 100 C.

In **roasting** meat the internal temperature reaches only about 60 C in rare beef, up to 80 C in well-done beef, and 85 C in a pork roast. **Frying** gets the outside of the food very hot, but the center ordinarily does not reach 100 C. **Cooking** is an indefinite term with little meaning. In the food industry, however, the term "cook" implies a specific time and temperature for a thermal process. **Warming up** a food may mean anything from a small increase in temperature up to heating to 100 C.

❑ Heating above 100 C

Temperatures above 100 C usually are obtained by means of steam under pressure in steam-pressure sterilizers or retorts. The temperature in the retorts increases with rising steam pressures. Thus with no pressure the temperature at sea level is 100 C; with 5 lb of pressure, 109 C; with 10 lb, 115.5 C; and with 15 lb, 121.5 C. When liquid foods are to be sterilized before their introduction into sterile cans, high steam pressures are used to apply a high temperature for a few seconds.

Milk can be heated to temperatures up to 150 C by use of steam injection or steam infusion followed by "flash evaporation" of the condensed steam and rapid cooling. Processes such as this for milk have been referred to as ultrahigh-temperature, or UHT, processes. With sufficient holding times on the order of several seconds, the process would "sterilize" the milk.

Heat treatments used in the processing of canned foods will be discussed further in the following section.

❑ Canning

Canning is defined as the preservation of foods in sealed containers and usually implies heat treatment as the principal factor in the prevention of spoilage. Most canning is in "tin cans," which are made of tin-coated steel, or in glass containers, but increasing use is being made of containers that are partially or wholly of aluminum, of plastics as pouches or solid containers, or of a composite of materials. Therefore, the word "canning" is a general term and is often replaced by "hermetically sealed containers."

Spallanzani in 1765 preserved food by heating it in a sealed container. Other workers, as well, had employed heat processes in attempts to prevent the spoilage of food, but it remained for a Frenchman, Nicolas Appert, who has been called the "father of canning," to experiment on the heating of foods in sealed containers and to publish directions for preservation by canning. His work, mostly in the years 1795 to 1810, was prompted by the offer of a prize by the French government for a published method for preserving foods for the armed forces. Appert won the 12,000 francs in 1809 for a treatise that was published a year later under the name The Book for All Households; or the Art of Preserving Animal and Vegetable Substances for Many Years. Appert gave exact directions for the preservation of a wide variety of foods in cork-stoppered, wide-mouthed glass bottles, which he heated for hours in boiling water. Nothing was known at the time about the relationship of microorganisms to the spoilage of foods, yet Appert worked out methods that were good enough to be followed for years after by home and commercial canners, who referred to the process as "Appertization".

been experimental.

❑ Pressurized Packaged Foods

Pressurized packaged liquids or pastes, called aerosols, are packed under pressure of a propellant gas, usually carbon dioxide, nitrogen, or nitrous oxide, so as to dispense

the food as a foam, spray, or liquid. Many foods are now being so packaged, e.g., whipped cream and other toppings, beverage concentrates, salad dressings, condiments, oils, jellies, and flavoring substances. The pressurized foods are subject to microbial spoilage unless adequate preservative methods are employed. Acid foods may be heated, canned, and then gassed, but the gassing process may contaminate the food. Aseptic canning is a possibility for low- and medium-acid foods. Process requirements for pasteurized foods, e.g., whipped cream and other toppings, are similar with or without gas pressure. The gas used as a propellant may have an influence on the kinds of organisms likely to grow. Nitrogen, for example, would not inhibit aerobes if a little oxygen were present, but carbon dioxide would be inhibitory under the same condition. Carbon dioxide under pressure inhibits many microorganisms, including aerobic bacteria and molds, but does not inhibit lactic acid bacteria, *Bacillus coagulans*, *Streptococcus faecalis*, or yeasts. Nitrous oxide represses some fungi.

❑ The Cooling Process

Following the application of heat, the containers of food are cooled as rapidly as is practicable. The cans may be cooled in the retort or in tanks by immersion in cold water or by a spray of water. Glass containers and large cans are cooled more gradually to avoid undue strain or even breakage. This tempering process involves the use of warm water (or spray), the temperature of which is lowered as cooling progresses. Final cooling of containers usually is by means of air currents.

The leakage of cooling water through imperfections in the container or its seal and the resultant spoilage will be discussed later (Chapter 19).