Section I

Principles and Establishments Classification
1 Fundamentals of Food Manufacturing

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1.1 INTRODUCTION AND GOALS

This chapter provides an overview of the basic principles of food manufacturing (processing). The goals of modern food manufacturing can be summarized as follows:

- **Formulation.** A logical basic sequence of steps to produce an acceptable and quality food product from raw materials.

- **Easy Manufacturing Procedures.** Development of methods that can facilitate the various steps of production.

- **Time Economy.** A cohesive plan that combines the science of production and manual labor to reduce the time needed to produce the product.
- **Consistency.** Application of modern science and technology to ensure the consistency of each batch of products.

- **Product and Worker Safety.** Close working relationship between government and manufacturers (processors), ensuring wholesome products for public consumption and a safe working environment for workers.

- **Buyer Friendly.** Assuming the buyer likes the product, the manufacturer must do everything humanly possible to ensure that the product is user friendly (size, cooking instruction, keeping quality, convenience, etc.).

Obviously, to achieve all the above goals is not a simple matter. This chapter is concerned mainly with the scientific principles of manufacturing safe food products. With this as a premise, the first question we can ask ourselves is the following: Why do we want to manufacture (process) food? At present, there are many modern reasons why foods are manufactured, for example, adding value to a food, improving the visual appeal, convenience. However, traditionally, the single most important reason that we wish to manufacture (process) food is to make it last longer without spoiling. Probably the oldest methods of achieving this goal are drying of cereals, fruits, and vegetables, salting of meat and fish, fermenting of milk, and pickling of vegetables. The next section discusses food spoilage and foodborne diseases.

### 1.2 FOOD SPOILAGE AND FOODBORNE DISEASES

#### 1.2.1 Food Spoilage

Foods are made from natural materials, and, like any living matter, will deteriorate in time. The deterioration of food, or food spoilage, is the natural way of recycling, restoring carbon, phosphorus, and nitrogenous matters to the good Earth. However, spoilage (deterioration, putrefaction) will usually modify the quality of foods from good to bad, in the form of poor appearance (discoloration), offensive smell, and inferior taste. Food spoilage could be caused by a number of factors, chiefly biological, but also by chemical and physical factors. Consumption of spoiled foods can cause sickness, and even death. Thus, food safety is the major concern in spoiled foods.

#### 1.2.1.1 Food Spoilage and Biological Factors

Manufactured (processed) and natural foods are composed mainly of carbohydrates, proteins, and lipids (fats and oils). The major constituents in vegetables and fruits are carbohydrates, including sugars (sucrose, glucose, and so on), polymers of sugars (starch), and other complex carbohydrates such as fibers. Lipids are the major components of oilseeds, milk and most cheeses, and proteins are the chief constituents of muscle foods. Under natural storage conditions, foods start to deteriorate once the living cells in the foods (of plant and animal origins) are dead or damaged. Secretion of internal proteases such as chymotrypsin and trypsin breaks up proteins at specific amino-acid positions, lipases and lyases from lyzosomes disintegrate the cells, de-esterificate fats (triglycerides) into fatty acids and glycerol, hydrolases hydrolyze proteins into amino acids, and starch into simpler sugars. The exposure of foods and damaged cells to the environment would attract microorganisms (e.g., bacteria, molds, and viruses), and insects, which in turn would further accelerate the decomposition of the food. Foods with contaminated microorganisms lead to foodborne illnesses, which, as reported by the Center for Disease Control and
Prevention (CDC), causes approximately 76 million illnesses and 5000 deaths in the United States yearly (http://www.cdc.gov/foodsafety/). For most food poisoning, the spoilage has not reached the stage where the sensory attributes (appearance, smell, taste, texture, and so on.) of the food are abnormal.

Illness from food can be mainly classified as:

- Foodborne infection caused by pathogenic bacteria (disease-causing microorganisms, such as *Salmonella* bacteria, multiplying in a victim’s digestive tract, causing diarrhea, vomiting, and fever, and so on), and
- Foodborne intoxication (food poisoning resulting from a toxin produced by pathogenic microorganisms, for example, *Clostridium botulinum* and *Staphylococcus aureus*, in the food itself).

Foodborne illness also has a major economic impact on society, costing billions of dollars each year in the form of medical bills, lost work time, and reduced productivity (McSwane and others 2003). Some genera of bacteria found in certain food types are listed in Table 1.1, and some common types of microorganisms found in foods are listed in Table 1.2. Some major bacterial and viral diseases transmitted to humans through foods are listed in Table 1.3. The interactive behavior of microorganisms may contribute to their growth and/or spoilage activity (Gram and others 2002).

### 1.2.1.2 Food Spoilage and Chemical (Including Biochemical) Factors

In many cases, when foods are oxidized, they become less desirable or are even rejected. The odor, taste, and color may change and some nutrients may be destroyed. Examples

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#### TABLE 1.1 Most Common Bacteria Genera Found in Certain Food Types.

<table>
<thead>
<tr>
<th>Microorganisms</th>
<th>Foods</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corynebacterium, Leuconostoc</td>
<td>Dairy products</td>
</tr>
<tr>
<td>Achromobacter</td>
<td>Meat, poultry, seafoods</td>
</tr>
<tr>
<td>Bacteriodes, Proteus</td>
<td>Eggs and meats</td>
</tr>
<tr>
<td>Pseudomonas</td>
<td>Meats, poultry, eggs</td>
</tr>
</tbody>
</table>

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#### TABLE 1.2 Most Common Pathogenic Bacteria and Viruses Found in Foods.

<table>
<thead>
<tr>
<th>Bacteria</th>
<th>Viruses</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Clostridium botulinum</em></td>
<td><em>Listeria monocytogenes</em></td>
</tr>
<tr>
<td><em>Salmonella</em> spp.</td>
<td><em>Staphylococcus aureus</em></td>
</tr>
<tr>
<td><em>Clostridium perfringens</em></td>
<td><em>Escherichia coli</em></td>
</tr>
<tr>
<td><em>Botulinum</em> spp.</td>
<td><em>Campylobacter jejuni</em></td>
</tr>
<tr>
<td><em>Streptococci</em> spp.</td>
<td><em>Bacillus cereus</em></td>
</tr>
<tr>
<td><em>Lactobacillus</em> spp.</td>
<td><em>Proteus</em> spp.</td>
</tr>
<tr>
<td><em>Salmonella</em> spp.</td>
<td><em>Vibrio</em> spp.</td>
</tr>
<tr>
<td><em>Hepatitis A virus</em></td>
<td><em>Echovirus</em></td>
</tr>
<tr>
<td><em>Rotaviruse</em></td>
<td><em>Calciviruse</em></td>
</tr>
</tbody>
</table>
are the darkening of the cut surface of a potato and the browning of tea color with time. Oxidative rancidity results from the liberation of odorous products during breakdown of unsaturated fatty acids. These products include aldehydes, ketones, and shorter-chain fatty acids.

Browning reactions in foods include three nonenzymatic reactions (Maillard, caramelization, and ascorbic acid oxidation), and one enzymatic reaction (phenolase browning) (Fennema 1985). Heating conditions in the surface layers of food cause the Maillard browning reaction between sugars and amino acids, for example, in the browning of baked bread and cakes. The high temperatures and low moisture content in the surface layers also cause caramelization of sugars, and oxidation of fatty acids to other chemicals such as aldehydes, lactones, ketones, alcohols, and esters (Fellows 1992). Moisture and heat can also produce hydrolytic rancidity in fats, in this case fats are split into free fatty acids, which may cause off-odors and rancid flavors in fats and oils (Potter and Hotchkiss 1995). Thermal decomposition of ascorbic acid under both aerobic and anaerobic conditions, by oxidative or nonoxidative mechanisms, in either the absence or presence of amino compounds, can also cause browning (Wedzicha and McWeeny 1974). The formation of ripening fruit flavor often results from Strecker degradation (the transamination and decarboxylation) of amino acids, such as the production of 3-methylbutyrate (apple-like flavor) from leucine (Drawert 1975). Further heating of the foods can break down some of the volatiles generated by the Maillard reaction and Strecker degradation to produce burnt or smoky aromas associated with browning. Enzymatic browning occurs on cut surfaces of light-colored fruits (apples, bananas) and vegetables (potatoes), due to the enzymatic oxidation of phenols to orthoquinones, which in turn rapidly polymerize to form brown pigments known as melanins.

1.2.1.3 Food Spoilage and Physical Factors. Food spoilage can also be caused by physical factors, such as temperature, moisture, and pressure acting upon the foods. Moisture and heat can also produce hydrolytic rancidity in fats (mentioned earlier), with production of off-odors and rancid flavors in fats and oils as mentioned earlier (Potter and Hotchkiss 1995). Excessive heat denatures proteins, breaks emulsions, removes moisture from food, and destroys nutrients such as vitamins. However, excessive coldness, such as freezing, changes their texture and/or cracks their outer coatings to permit contamination by microorganisms. Foods under pressure will be squeezed and transform
into unnatural conformation. The compression will likely break up the surface structure (cracking of eggs), release degradative enzymes (bruising of fruits such as apples and pears), and expose the damaged food to exterior microbial contamination.

Of course, many health officials consider physical factors to include such things as sand, glass, wood chip, rat hair, animal urine, bird droppings, insect parts, and so on. They may not spoil the food, but they can present health hazards. Some of these foreign substances do lead to spoilage. Insects and rodents can consume and damage stored foods, and insects can lay eggs and leave larvae in the foods, causing further damage later. Such foods are no longer reliable because they contain hidden contaminants. The attack of foods by insects and rodents can also contaminate foods further with microbial infections.

1.2.1.4 Prevention and Retardation of Food Spoilage. Food spoilage can be prevented by proper sanitary practices in food handling and processing, appropriate preservation techniques, and standardized storing conditions.

Food Handling and Processing. The entire process, from raw ingredients to a finished product for storage, must comply with a standard sanitation program. In the United States, the practice of HACCP (hazard analysis critical control points), mandatory at present for several industries, may eventually become so for all food industries. At present, the application of HACCP is voluntary for most food processors. Similar sanitary programs apply to workers. It is important to realize that a food processing plant must have a basic sanitation system program before it can implement a HACCP program.

Food Preservation. There are many techniques used to preserve food, such as legal food additives, varying levels of food ingredients or components, traditional and new technologies. Legal food additives, among other functions, can prevent oxidation and inhibit or destroy harmful microorganisms (molds and bacteria). Vitamin E or vitamin C can serve as antioxidants in many food products and benzoate in beverages can act as an antimicrobial agent. We can preserve food by manipulating the levels of food ingredients or components to inhibit the growth of microorganisms or destroy them, for example, by keeping the food low in moisture content (low water activity), high in sugar or salt content, or at a low pH (less than pH 5). Other traditional technologies such as canning (thermal processing), fermentation, refrigeration, and freezing are well-established preservation methods. Recently, new or alternative technologies have become available to preserve food. Because they are new, their applications are carefully monitored. Nothing in the last two decades seems to have generated more publicity than the use of X-rays in food processing. Although food irradiation has been permitted in the processing of several categories of food, its general application is still carefully regulated in the United States.

Food Packaging and Storage. Raw and processed foods should be packaged to prevent oxidation and microbial contamination, insect infestation, and loss of moisture and integrity. Storage of foods (when not contaminated) below −20°C can allow food to be kept for several months or a year. Foods stored at 4°C can have their shelf-life extended to several days or a week (note that some bacteria such as *Listeria monocytogenes* can still grow and multiply even in foods at refrigerated temperatures).

Newly developed techniques to preserve foods include the incorporation of bacteriocin in plastic to retain activity and to inhibit surface growth of bacteria on meat (Siragusa and others 1999), and the application of an intelligent Shelf Life Decision System for quality optimization of the food chill chain (Giannakourou and others 2001).
1.2.1.5 **Sources of Information.** At present, all major Western government authorities have established Web sites to educate consumers and scientists on the safe processing of food products. Internationally, two major organizations have always been authoritative sources of information: World Health Organization (WHO) and Food and Agriculture Organization (FAO). They also have comprehensive Web sites.

In the United States, major federal authorities on food safety include, but are not limited to the following:

- Department of Agriculture (USDA),
- Food and Drug Administration (FDA),
- Centers for Disease Control (CDC),
- Environmental Protection Agency (EPA),
- National Institutes of Health (NIH).

Many trade associations in Western countries have Web sites that are devoted entirely to food safety. Some examples in the United States include

- American Society of Microbiologists,
- Institute of Food Technologists,
- International Association of Food Protection,
- National Food Processors Association,
- Food Products Association,
- National Restaurants Association.

All government or trade association Web sites are easily accessible by entering the agency name into search engines.

1.3 **PRODUCT FORMULATIONS AND FLOW CHARTS**

As mentioned earlier, for many food products, processing is an important way to preserve the product. However, for some food products, many self-preserving factors play a role, such as ingredients and their natural properties. Three good examples are pickles, barbecue sauces, and hard candies. Preserving pickles is not difficult if the end product is very sour (acidic) or salty. Traditionally, barbecue sauces have a long shelf-life because of the high content of sugar and acids. Most unwrapped hard candies keep a long time, assuming the environment is at room temperature and not very humid. Most wrapped hard candies last even longer if the integrity of the wrappers is maintained. For baked products (cookies, bread), measures against spoilage take second place to consumer acceptance of freshness. So, the objectives of processing of foods vary with the product. However, one aspect is essential to all manufacturers, as discussed below.

To manufacture a food product, it is assumed that the manufacturer (processor) has a formula for the product. In countries all over the world, small family-owned food businesses usually start with home recipes for popular products instead of a scientific formula. Most of us are aware of such humble beginnings of major corporations manufacturing cola (carbonated), soft drinks, cheeses, breakfast cereals, and many others. When these family businesses were started, there was not much science and technology involved.
As the companies grew and had many employees, they started to hire food scientists, food technologists, and food engineers to study the “recipe(s)” and refine every aspect of the product until the entire manufacturing process was based on sound scientific, technical, and engineering principles. After that, all efforts were directed towards production and marketing. Even now, somewhere a person will start making “barbecue sauce” in his garage and selling it to his neighbors. Although very few of these starters will succeed, this trend will continue to be the case in view of the free enterprise spirit of the West.

Although any person can start manufacturing food using a home recipe, the federal government in the United States has partial or total control over certain aspects of the manufacturing processes for food and beverage products. This control will automatically affect the recipes, formulas, or specifications of the products. Although the word “control” here refers mainly to safety, it is understood that it will affect the formulations to some extent, especially critical factors such as temperature, pH, water activity, and so on.

Flow charts differ from formula in that they provide an overview of the manufacturing process. For illustration, Figures 1.1 to 1.8 provide examples of flow charts for the manufacture of bakery (bread), dairy (yogurt), grain (flour), fruits (raisins), vegetables (pickles), meat (frankfurters, frozen chicken parts), and seafood (canned tuna).
1.4 UNITS OF OPERATIONS

The manufacturing (processing) of most food products involves many of the following unit operations:

- Raw materials,
- Cleaning,
- Separating,
- Disintegrating,
- Forming, raw,
- Pumping,
Figure 1.3  A general flow chart for the production of flour from wheat.
Figure 1.4  A general flow chart for the production of raisins.
Figure 1.5 A general flow chart for the production of pickles.
1.4 UNITS OF OPERATIONS

- Mixing,
- Application methods (formulations, additives, heat, cold, evaporation, drying, fermenting, and so on),
- Combined operations,
- Forming, finished product.

Figure 1.6 A general flow chart for the production of Frankfurters.
Instead of classifying the following as units of operations, we will discuss them and similar procedure as separate topics:

- Heating,
- Cooling,
- Sanitation,
- Quality control,
- Packaging.
According to the United States Department of Labor, there are hundreds of different categories of food products being manufactured. Correspondingly, there are hundreds of companies manufacturing each category of food product. In sum, there are literally thousands of food manufacturers. Two major reasons for this explosion of new companies are the constant introduction of new products and improvement in manufacturing methods and equipment.

To facilitate the technological processing of food at educational and commercial levels, food manufacturing (processing) professionals have developed unified principles and a systematic approach to the study of these operations. The involved processes of the food industry can be divided into a number of common operations, termed unit operations. Depending on the manufacturer (processor), such unit operations vary in name and

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**Figure 1.8** A general flow chart for the production of canned tuna.
number. For ease of discussion, we use the following unit operations (in alphabetical order) for the most common ones:

- Cleaning,
- Coating,
- Controlling,
- Decorating,
- Disintegrating,
- Drying,
- Evaporating,
- Forming,
- Heating,
- Mixing,
- Packaging,
- Pumping,
- Raw materials handling,
- Separating.

During food processing, the manufacturer selects and combines unit operations into unit processes, which are then combined to produce more complex and comprehensive processes. Although emerging technology plays an important role in food processing as time progresses, these units, in the order they appear in a food processing plant, still apply.

1.4.1 Raw Materials Handling

Raw materials are handled in various ways, including:

- Hand and mechanical harvesting on the farm;
- Trucking (with or without refrigeration) of fruits and vegetables;
- Moving live cattle by rail; and
- Conveying flour from transporting vehicle or boats to storage bins.

Some good examples are as follows.

- Oranges are picked on the farm by hand or mechanical devices, moved by truck trailers, usually refrigerated, to juice processing plants, where they are processed. Of course, the transport must take into account the size of the trucks, length of time during transport, and temperature control. The major objective is to avoid spoilage. In recent years, the use of modified atmosphere packaging/storage has increased the odds in favor of the farmers and producers.

- Handling sugar and flour poses great challenges. When dry sugar reaches the processing plants, via truck trailers or rail, it is transported to storage bins via a pneumatic lift system. The sugar will cake if the storage time, temperature, and humidity are not appropriate. Improper transfer of sugar may result in dusting and buildup of static electricity, which can cause an explosion, because sugar particles are highly combustible. The same applies to finely divided flour.
In handling raw materials, one wishes to achieve the following major objectives:

- Proper sanitation;
- Minimal loss of product;
- Acceptable product quality;
- Minimal bacterial growth,
- Minimal holding time.

### 1.4.2 Cleaning

We all know what cleaning a raw product means. Before we eat a peach, we rinse it under the faucet or with potable water. Before we make a salad, we wash/rinse the vegetables with potable water. Before we eat crabs, we clean them. Of course, the difference in cleaning between home kitchens and a food processing plant is the volume. We clean one peach; they clean a thousand peaches.

Depending upon the product and the nature of the dirt, cleaning can be accomplished with the following methods or devices, individually or in combination:

- Air (high-velocity),
- Brushes,
- Magnets,
- Steam,
- Ultraviolet light,
- Ultraviolet sound,
- Vacuum,
- Water.

There are other new technologies that will not be discussed here.

Water is probably the most common cleaning agent and its applications vary. Examples include the following:

- Clams, oysters, crabs, and other shellfish are commonly hosed to remove mud, soil, and other foreign debris. If they are contaminated, they may have to be purged by incubating them in running clean seawater.
- City water will not be acceptable for manufacturing beverages. It will have to be further treated with chemical flocculation, sand filtration, carbon purification, microfiltration, deaeration, and so on. This is not considered a simple cleaning. Rather it is a process in cleaning.
- Eviscerating poultry can be considered a cleaning operation if we make use of water. However, the actual process of removing the entrails may involve vacuuming in addition to water.
- With a product like pineapple, the irregular surface is usually cleaned by the scrubbing action of high-pressure water jets.

Just as in a home kitchen where pots and pans require frequent cleaning, state and federal regulations require that the equipment used in a food processing plant be
cleaned and sanitized after each use. After dirt and mud are removed, some raw products also require special sanitizing procedures. The use of sanitizers can be a complicated matter involving different types of sanitizers, federal regulations, expertise, and so on.

1.4.3 Separating
In food processing, the step of separating may involve separating

- A solid from a solid, as in peeling of potatoes;
- A solid from a liquid, as in filtration;
- A liquid from a solid, as in pressing juice from a fruit;
- A liquid from a liquid, as in centrifuging oil from water;
- A gas from a solid or a liquid, as in vacuum canning.

One of the time-honored techniques in the separating operation is the hand sorting and grading of individual units, such as mushrooms, tomatoes, oranges. Many mechanical and electronic sorting devices have now replaced human hands in handling various types of raw food products. An electronic eye can identify differences in color as the products are going along the conveyor belt. Built-in mechanisms can sort the products by color, into “good” versus “bad” color. The current invention of the electronic nose also shows promises, and automatic separation according to size is easily accomplished by passing fruits or vegetables over differently sized screens, holes, or slits.

1.4.4 Disintegrating
Disintegrating means subdividing large masses of foods into smaller units or particles. This may include

- Cutting;
- Grinding;
- Pulping, homogenizing; or
- Other methods.

Examples include

- Automatic dicing of vegetables;
- Mechanical deboning of meat;
- Manual and automatic cutting of meat into wholesale and retail sizes;
- Cutting of bakery products with electric knives and other products with water jets (high-velocity and high-pressure);
- Disintegrating various categories of food products with high-energy beams and laser beams;
Homogenization using commercial blenders, high-pressure traveling through a valve with very small openings, ultrasonic energy, and so on. Homogenization is probably one of the most important stages (if not the most important) in dairy manufacturing. Homogenization produces disintegration of fat globules in milk or cream from large globules and clusters into minute globules. This is done by forcing the milk or cream under high pressure through a valve with very small openings.

1.4.5 Forming

Forming is an important operation in manufacturing many foods:

- Meat and poultry patties;
- Confections such as candies, jelly beans, fruit juice tablets;
- Breakfast cereals;
- Pasta;
- Kinds such as some cheese cubes, processed cheese slices, potato chips, and others.

1.4.5.1 Meat and Poultry Patties.

Patty-making machines are responsible for making ground meat and poultry patties by gently compacting the product into a disk shape. Uniform pressure is applied to produce patties with minimal variation in weight. Excessive pressure may result in tough cooked patties.

1.4.5.2 Pasta.

Pasta products are formed by forcing dough through extrusion dies of various forms and shapes before drying in an oven.

1.4.5.3 Confectionery.

The shapes and forms in the confectionery industry, such as candies and jellies, are made in several ways. Two of the most popular methods are the use of molds and cutting:

- Molds. The traditional use of molds is applied in making confectionery such as fondants, chocolate, and jellies. The product is deposited into molds to cool and harden.
- Cutting. Hard candies and toffee are cut into pieces after kneading or pulling.

1.4.6 Pumping

In food processing, pumping moves food (liquid, semi-solid, paste, or solid) from one step to the next or from one location to another. There are many types of pumps available, some with general, others specialized, applicability. The type of pump used depends on the food (texture, size, etc.). For example, broth, tomato pastes, ground meat, corn kernels, grapes, and other categories of food all require a “different” pump to do the job. Two of the most important properties of pumps are the ability to break up foods, and ease of cleaning.
1.4.7 Mixing

The operation of mixing, for example, includes

- Kneading,
- Agitating,
- Blending,
- Emulsifying,
- Homogenizing,
- Diffusing,
- Dispersing,
- Stirring,
- Beating,
- Whipping, and
- Movements by hands and machines.

Examples of mixing include

- Homogenization to prevent fat separation in milk;
- Mixing and developing bread dough, which requires stretching and folding, referred to as kneading;
- Beating in air, as in making an egg-white foam;
- Blending dry ingredients, as in preparing a ton of dry cake mix;
- Emulsifying, as in the case of mayonnaise.

Commercial mixers for food processing come in many shapes and forms because many types of mixtures or mixings are possible. Two examples are provided as illustration:

1. Mixing solids with solids, for example, a dry cake mix. The mixer must cut the shortening into the flour, sugar, and other dry ingredients in order to produce a fluffy homogeneous dry mix. A ribbon blender is used.

2. Beating air into a product while mixing, for example, using a mixer-beater in an ice-cream freezer. The mixer turns in the bowl in which the ice-cream mix is being frozen. This particular operation permits the mixer to achieve several tasks or objectives: it beats air into the ice-cream to give the desired volume and overrun, and it keeps the freezing mass moving to produce uniformity and facilitate freezing.

1.5 PROCESSING AND PRESERVATION TECHNIQUES

1.5.1 Heat Application

Heat exchanging, or heating, is one of the most common procedures used in the manufacture of processed foods. Examples include pasteurizing of milk, manufacturing of bakery products, roasting peanuts, and canning. Foods may be heated or cooked using

- Direct injection of steam,
- Direct contact with flame,
Toasters,
Electronic energy as in microwave cookers, and
Many new forms of technology.

Whatever the method, precise control of temperature is essential. Heating is used in

- Baking,
- Frying,
- Food concentration,
- Food dehydration, and
- Package closure.

1.5.1.1 Why are Foods Heated? All of us know why we cook food at home: to improve texture, to develop flavors, to facilitate mixing of water, oil, and starch, to permit caramelization, and so on. Commercially, the basic reasons for heating are simple and may include the following:

1. Destruction of microorganisms and preservation of food (food canning and milk pasteurization are common examples);
2. Removal of moisture and development of flavors (ready-to-eat breakfast cereals and coffee roasting are common examples);
3. Inactivation of natural toxicants (processing soy-bean meal is a good example);
4. Improvement of the sensory attributes of the food such as color, texture, and mouth-feel;
5. Combination of ingredients to develop unique food attributes and to attract consumer preferences.

Traditional thermal processing of foods uses the principles of transferring heat energy by conduction, convection, radiation, or a combination of these. Foods are heated in a variety of traditional equipment by applying basic food engineering principles using heat exchangers, tanks or kettles, retorts, and Toasters. Other methods may include direct injection of steam, and direct contact with flame. Heating food with electronic energy (microwave) is a relatively new technique. Later in this chapter, other new technologies for heating foods will be discussed.

1.5.1.2 Heat Exchangers for Liquid Foods. As foods are sensitive to heat, special consideration is needed. Dark color, burnt flavors, and loss of nutrients can result from heating, especially prolonged heating. Heat exchangers have special advantages. They permit

1. Liquid food to have a maximal contact with the heat source and
2. Rapid heating and cooling.

For example, a plate-type heat exchanger is used to pasteurize milk. The equipment is composed of many thin plates. When milk flows through one side of the plates, it is heated by hot water on the other side. This provides maximal contact between the heat source and milk, resulting in rapid heating in a short time. The cooling is the reverse process after the milk has been heated. Instead of hot water, cooling water or brine is used.
1.5.1.3 Tanks or Kettles for Liquid Foods. During heating, hot water or pressurized steam circulating in the jackets of the tanks or kettles heats the food, and the reverse for cooling. This technique works for full liquid foods or partially liquid foods such as soups.

1.5.1.4 Pressure Cookers or Retorts for Packaged Foods. The most common method of sterilizing canned foods uses pressure cookers or retorts. Beginning in the early 1970s, the risk of botulism in canned food with low acidity prompted the U.S. FDA to implement stringent regulations governing this group of foods. Although the name of Hazards Analysis Critical Control Points (HACCP) did not have wide usage at the time, the regulations governing the production of low-acid canned foods can be considered the earliest form of HACCP program. Large pressure cookers or retorts are used to ensure that the canned goods are heated above the boiling point of water. The high temperature is generated by steam under pressure in a large retort designed to withstand such pressure and temperature. In this case, convection and conduction of heat energy are achieved. Steam hits the outside of the cans and energy is conducted into the can. Some form of moving or agitating device permits improved convection to occur inside the cans. Although there are other modern techniques of heating canned food products, many smaller companies still depend heavily on these traditional methods.

1.5.1.5 Roasters or Heated Vessels in Constant Rotation. Instead of one or two pieces of equipment, this system contains several units: loading containers, conveyor belts, hoppers, vats or vessels. The vessels are usually cylindrical in shape with built-in heating devices. Heat is generated via one of the following methods:

1. Circulation of heated air, which heats the food products inside the vessels;
2. Application of direct heat to the outside of the vessel by means of steam, flame (gas), and air (hot), for example, whereby heat is radiated from the inside walls of the vessels to the food.

The above unit system is best for roasting coffee beans or nuts.

1.5.1.6 Tunnel Ovens. This can be used for a variety of food products. The product is placed on a conveyor belt, which moves under a heat source. Sometimes, the product is vibrated so that heat distribution is even. Temperature control is essential, enabling products such as coffee beans or nuts to be roasted using this method.

1.5.2 Heat Removal or Cold Preservation

Cold preservation is a preservation method achieved by the removal of heat. It is among the oldest methods of preservation. Since 1875, with the development of mechanical ammonia refrigeration systems, commercial refrigeration and freezing processes have been available. A reduction in the temperature of a food reduces the rate of quality changes during storage caused by a number of factors. At low temperatures, microbial growth is retarded and its reproduction prevented. The rate of chemical reactions (e.g., oxidation, Maillard browning, formation of off-flavor), biochemical reactions (e.g., glycolysis, proteolysis, enzymatic browning, and lipolysis), and physical changes between
food components and the environment (e.g., moisture loss in drying out of vegetables) can also be reduced.

Most food spoilage organisms grow rapidly at temperatures above 10°C, although some grow at temperatures below 0°C, as long as there is unfrozen water available. Most pathogens do not grow well at refrigeration temperatures, except some psychrophilic bacteria such as *Listeria monocytogenes,* which commonly grows in dairy products. Below −9.5°C, there is no significant growth of spoilage or pathogenic microorganisms.

In general, the longer the storage period, the lower the temperature required. Pretreatment with intensive heat is not used in this process operation and, together with adequate control over enzymatic and microbiological changes, the food maintains its nutritional and sensory characteristics close to fresh status and results in a high-quality product. In comparing chilled and frozen foods, chilled food has a higher quality but a shorter shelf-life, and frozen food has a much longer shelf-life, but the presence of ice in the frozen product may contribute some undesirable changes in food quality.

1.5.2.1 Chilling and Refrigeration Process. The chilling process is the gentlest method of preservation, generating the least significant changes in taste, texture, nutritive value, and other attributes of foods. Generally it refers to a storage temperature above freezing, between about 16°C and −2°C. Most foods do not freeze until −2°C or slightly lower because of the presence of solutes such as sugars and salts. Commercial and household refrigerators usually operate at between 4.5°C and 7°C.

In low-acid chilled foods, strict hygienic processing and packaging areas required to ensure food safety. The chilling process is usually used in combination with other preservation methods such as fermentation, irradiation, pasteurization, mild heat treatment, chemicals (acids or antioxidants), and controlled atmosphere. The combination of these methods avoids the extreme conditions that must otherwise be used to limit microbial growth, thus providing a high-quality product (e.g., marinated mussels and yogurt).

Not all foods can be stored under chilled conditions. Tropical and subtropical fruits suffer chilling injury when stored below 13°C, resulting in abnormal physiological changes: skin blemishes (e.g., banana), browning in the flesh (e.g., mango), or failure to ripen (e.g., tomato). Some other foods should not be refrigerated; for example, breads stale faster at refrigeration temperature than at room temperature. Starch in puddings also tends to retrograde and result in syneresis.

There are several important considerations in producing and maintaining high-quality chilled foods.

1. Quick Removal of Heat at the Chilling Stage. Ideally, refrigeration of perishable foods starts at the time of harvest, slaughter, or at the finishing production line. Cooling can be accelerated by the following techniques.

   a. *Evaporative cooling:* Spray water and then subject food to vacuum (e.g., leafy vegetables).

   b. *Cryogenic cooling:* Nitrogen gas from evaporating liquid nitrogen, dry ice, and liquid carbon dioxide are used to remove heat for different products.

   c. *Heat exchangers:*

      i. Thin plates where warm bulk liquid foods pass chilled or “super-chilled” cooling fluid, separated by a thin stainless steel plate.

      ii. Cooling coils for liquid food.
2. Maintaining Low Temperature During the Chill Storage. This can be affected by the following factors:
   a. Refrigeration design (i.e., cooling capacity and insulation): This must be taken into account because temperature can be affected by heat generated by lights and electric motors, people working in the area, the number of doors and how they are opened, and the kinds and amounts of food products stored.
   b. Refrigeration load: Quantity of heat that must be removed from the product and the storage area in order to decrease from an initial temperature to the selected final temperature and then to maintain this temperature for a specific time.
   c. Types of food:
      i. Specific heat of food: Quantity of heat that must be removed from a food to lower it from one temperature to another. The rate of heat removal is largely dependent on water content.
      ii. Respiration rate of food: Some foods (fruits and vegetables) respire and produce their own heat at varying rates. Products with relatively high respiration rates (snap beans, sweet corn, green peas, spinach, and strawberries) are particularly difficult to store.

3. Maintaining Appropriate Air Circulation and Humidity. Proper air circulation helps to move heat away from the food surface toward refrigerator cooling coils and plates. Air velocity is important, especially in commercial coolers or freezers, in maintaining the appropriate relative humidity (RH), because if the RH is too high, condensation of moisture on the surface of cold food may occur, thus causing spoilage through microbial growth or clumping of the product. However, if RH is too low, dehydration of food may occur instead. Therefore, it is important to control the RH of the cooler and have proper packaging of food.

4. Modification of Gas Atmosphere. Chilled storage of fresh commodities is more effective if it is combined with control of the composition of the storage atmosphere. A reduction in oxygen concentration and/or increase in carbon dioxide concentration of the storage atmosphere reduces the rate of respiration (and thus maturation) of fresh fruits and vegetables, and also inhibits rates of oxidation, microbial, and insect growth. The atmospheric composition can be changed using three methods:
   a. Controlled Atmosphere Storage (CAS), where the concentration of oxygen, carbon dioxide, and ethylene are monitored and regulated throughout the storage. It is used to inhibit overripening of apples and other fruits in cold storage. Stored fruit and vegetables consume O₂ and give off CO₂ during respiration.
   b. Modified Atmosphere Storage (MAS), where the initially modified gas composition in a sealed storage is allowed to change by normal respiration of the food, but little control is exercised. The O₂ is reduced but not eliminated, and CO₂ is increased (the optimum levels differ for different fruits).
   c. Modified Atmosphere Packaging (MAP), where the fruit and vegetables are sealed in a package under flushed gas (N₂ or CO₂), and the air in the package is modified over time by the respiring product. Fresh meat (especially red meats) is packaged similarly.

5. Efficient Distribution Systems. To supply high-quality chilled foods to consumers, a reliable and efficient distribution system is also required. This involves chilled stores, refrigerated transportation, and chilled retail display cabinets. It requires careful control of the storage conditions, as above.
1.5.2.2 Freezing and Frozen Storage. Freezing is a unit operation in which the temperature of a food is reduced below the freezing point and a proportion of the water undergoes a phase change to form ice. Proper freezing preserves foods without causing major changes in their shape, texture, color, and flavor. Good frozen storage requires temperatures of \(-18^\circ\text{C}\) or below; however, it is cost prohibitive to store lower than \(-30^\circ\text{C}\). Frozen foods have increased in their share of sales since freezers and microwaves have become more available.

The major commodities commonly frozen are

- Fruits (berries, citrus, and tropical fruit), either whole, pureed, or as juice concentrate;
- Vegetables (peas, green beans, sweet corn, spinach, broccoli, Brussels sprouts, and potatoes such as French fries and hash browns);
- Fish fillets and seafoods, including fish fingers, fish cakes, shellfish, and prepared dishes with sauces;
- Meats (beef, lamb, and poultry) as carcasses, boxed joints, or cubes, and meat products (sausages and beef burgers);
- Baked goods (bread, cakes, pastry dough, and pies);
- Prepared foods (pizzas, desserts, ice cream, and dinner meals).

Principles of Freezing. The freezing process implies two linked processes: lowering of temperature by the removal of heat and a change of phase from liquid to solid. The change of water into ice results in an increase in concentration of the unfrozen matrix and therefore leads to dehydration and lowering of water activity. Both the lowering of temperature and water activity contribute to freezing as an important preservation method.

In order for a product to freeze, the product must be cooled below its freezing point. The freezing point of a food depends on its water content and the type of solutes present. The water component of a food freezes first and leaves the dissolved solids in a more concentrated solution, which requires a lower temperature to freeze. As a result, the freezing point decreases during freezing as the concentration increases. Different solutes depress the freezing point to a different degree.

Rate of Freezing. Faster freezing produces small crystals, necessary for high-quality products such as ice-cream. There are two main opposing forces affecting the freezing rate. The driving force includes the difference in temperatures between the freezing medium and the product; the bigger the difference, the faster the product will cool down. High thermal conductivity of the freezing medium (the efficiency with which the refrigerating agent extracts heat) and direct surface contact between medium and product also help to freeze the product quickly. On the other hand, the resistance force to quick freezing includes the product being packed in big sizes, irregular product geometry affecting direct contact with the freezing agent, and the product composition having a high heat capacity. Thermal conductivity of food packages such as cardboard and plastics will act to insulate heat transfer and thus slow down the freezing rate.

1.5.2.3 Quality Changes in Food as a Consequence of Freezing and Frozen Storage. As a consequence of the formation of ice, some negative changes in the quality of food result. The two major causes are freeze concentration effect and ice recrystallization.
Effect of Concentration of Solutes on Food Quality. The quality of products will change if solutes in the frozen product precipitate out of solution, for example, leading to a loss of consistency in reconstituted frozen orange juice because of aggregated pectic substances, and syneresis of starch pudding because of starch aggregation. The increase in ionic strength can lead to “salting out” of proteins, causing protein denaturation (a reason for the toughening of frozen fish). An increase in solute concentration may lead to the precipitation of some salts, and the anion/cation ratio of colloidal suspensions would then be disturbed and causes changes in pH. Such changes would also cause precipitation of proteins and changes in color of anthocyanin in berries. The concentration of solutes in the extracellular fluid will cause dehydration of adjacent tissues in fruit and vegetables, which would not be able to rehydrate after thawing. Lastly, the concentration of reactive compounds would accelerate reactions such as lipid oxidation.

Large Ice Crystal and Recrystallization Damage. If the food is not stored under sufficiently cold and steady temperatures, ice crystals will grow, or recrystallize to large ice crystals, which may cause damage to the food texture. Damage such as the physical rupture of cell walls and membranes and separation of plant and animal cells cause limp celery or green beans, and drips in thawed berries and meat. Enlarged ice crystals also disrupt emulsions (butter and milk), frozen foams (ice-cream), and gels (frozen pudding and pie fillings), thus making these frozen products less homogenous, creamy, and smooth.

Freezer Burn. Another quality damage relating to ice recrystallization is the freezer-burn problem. Freezer-burn occurs when there is a headspace in the packaged food and the food is subjected to fluctuating storage temperature. When the temperature increases, ice at the warmer surface will sublime into the headspace. As the temperature of the freezer or surroundings cools down, the water vapor will recrystallize on the inner surface of the package instead of going back into the product. This leads to dehydration of the surface of the product. If the frozen product is not packaged, the freezer-burn problem is more common and more severe.

1.5.2.4 Types of Common Freezers with Different Cooling Media

1. Cold air Freezers.
   a. Blast/belt freezers are large insulated tunnels in which air as cold as \(-40^\circ\text{C}\) is circulated to remove heat. The process is cheap, simple, and geared toward high-volume production. Rotating spiral tiers and multilayered belts are incorporated to move product through quickly and avoid “hot spots”.
   b. Fluidized bed freezers are modified blast freezers in which cold air is passed at a high velocity through a bed of food, contained on a perforated conveyor belt. This produces a high freezing rate, but is restricted to particulate foods (peas, shrimp, and strawberries).

2. Cold Surface Freezers.
   a. Plate freezers work by increasing the amount of surface area that comes into direct contact with the product to be frozen. Typically, refrigerant runs in the coils that run through plates or drums on which products are laid out. Double-plated systems further increase the rate of heat transfer to obtain higher
quality. This system is suitable for flat and uniform products such as fish fillets, beef burgers, and dinner meals.

b. **Scraped-surface freezers** work by having a liquid or semisolid food (ice-cream) frozen onto the surface of the freezer vessel, and a rotor scrapes the frozen portion from the wall. Typically, ice-cream is only partially frozen in a scraped-surface freezer to about \(-6^\circ C\), and the final freezing is completed in a hardening room (\(-30^\circ C\)).

3. **Cold Liquid Freezers.** Brine freezers using supersaturated solutions for maximum surface contact immerse the product in a liquid freezing agent, in particular for irregularly shaped product, such as crabs. Their main disadvantage is that products are subject to absorption of salt as well as bacteria if not properly packed.

4. **Cryogenic Freezer.** Liquid nitrogen or liquid carbon dioxide (which vaporize at \(-178^\circ C\) and \(-80^\circ C\), respectively), freeze product extremely quickly. This is only suitable for freezing premium products such as shrimp and crab legs because of the high cost of the nonrecoverable gas.

Tips for obtaining top-quality frozen product include the following:

- Start with high-quality product – freezing can maintain quality but not enhance it.
- Get the heat out quickly, by removing any nonedible parts from the food.
- Maintain the integrity of the frozen product – proper cutting and packaging avoids drips.
- Store the product at the coldest temperature economically possible, in a well-designed and maintained facility. Use proper inventory techniques to avoid deterioration.
- Avoid temperature fluctuation during storage and shipping.

### 1.5.3 Evaporation and Drying

During food processing, evaporation is used to achieve the following goals:

- Concentrate food by partial removal of water;
- Remove undesirable food volatiles;
- Recover desirable food volatiles.

Traditionally, evaporation is achieved via the following methods:

- Using solar energy to evaporate water from seawater to recover the salts left behind;
- Using a heated kettle or similar equipment to boil water from liquid or semisolid foods, for example, sugar syrup;
- Using the improved method of evaporating under a vacuum, where the term vacuum evaporator refers to a closed heated kettle or similar equipment connected to a vacuum pump. One principle to remember is that a major objective of vacuum evaporators is to remove water at temperatures low enough to avoid heat damage to the food.

There are, at present, many specialized pieces of equipment used for evaporating food products. However, overall, the above three methods are most common.
Drying differs from evaporating in that the former takes the food to nearly total dryness or the equivalence of 97% or 98% solids. The oldest method of drying food is to put the food under the hot sun. This practice probably started thousands of years ago. Although sun drying is still practiced, especially in many Third World countries, modern food drying has been modified to a nearly exact science. Drying has multiple objectives:

- To preserve the food from spoilage;
- To reduce the weight and bulk of the food;
- To make the food enjoy an availability and consumption pleasure similar to canned goods;
- To develop “new” or “novelty” items such as snacks.

Some well-known products prepared from drying include

- Dried milk powder,
- Instant coffee,
- Fish and shellfish,
- Jerky,
- Dried fruits, and
- Dried potato flakes.

The central equipment in drying food is the dryer. There are many types of dryer: spray dryers, drum dryers, roller dryers, and others, each of which can be used to meet specific needs.

1.5.4 Food Additives

One popular method of food preservation is the addition of chemicals, legally known as food additives in the United States. In January of 1992, the U.S. FDA and the International Food Information Council released a brochure presenting an overview of food additives. The information in this section has been derived from this document, with an update.

Perhaps the main functional objectives of the use of food additives are the following:

- What keeps bread mold-free and salad dressings from separating?
- What helps cake batters rise reliably during baking and keeps cured meats safe to eat?
- What improves the nutritional value of biscuits and pasta, and gives gingerbread its distinctive flavor?
- What gives margarine its pleasing yellow color and prevents salt from becoming lumpy in its shaker?
- What allows many foods to be available year-round, in great quantity, and with the best quality?

Food additives play a vital role in today’s bountiful and nutritious food supply. They allow our growing urban population to enjoy a variety of safe, wholesome, and tasty foods, year-round. Also, they make possible an array of convenience foods without the inconvenience of daily shopping.

Although salt, baking soda, vanilla, and yeast are commonly used in foods today, many people tend to think of any additive added to foods as being a complex and sometimes
harmful chemical compound. All food additives are carefully regulated by federal authorities and various international organizations to ensure that foods are safe to eat and are accurately labeled. The purpose of the brochure from which this information is taken is to provide helpful background information about food additives, why they are used in foods, and how regulations govern their safe use in the food supply.

1.5.4.1 Why are Additives Used in Foods? Additives perform a variety of useful functions in foods that are often taken for granted. As most people no longer live on farms, additives help keep food wholesome and appealing while en route to markets sometimes thousands of miles away from where it is grown or manufactured. Additives also improve the nutritional value of certain foods and can make them more appealing by improving their taste, texture, consistency, or color.

Some additives could be eliminated if we were willing to grow our own food, harvest and grind it, spend many hours on cooking, or accept increased risks of food spoilage. However, most people today have come to rely on the many technological, aesthetic, and convenience benefits that additives provide in food.

Additives are used in foods for five main reasons.

- **To Maintain Product Consistency.** Emulsifiers give products a consistent texture and prevent them from separating. Stabilizers and thickeners give smooth uniform texture. Anticaking agents help substances such as salt to flow freely.

- **To Improve or Maintain Nutritional Value.** Vitamins and minerals are added to many common foods such as milk, flour, cereal, and margarine to make up for those likely to be lacking in a person’s diet or lost in manufacturing. Such fortification and enrichment have helped reduce malnutrition in the U.S. population. All products containing added nutrients must be appropriately labeled.

- **To Maintain Palatability and Wholesomeness.** Preservatives retard product spoilage caused by mold, bacteria, fungi, yeast, or air. Bacterial contamination can cause foodborne illness, including the life-threatening botulism. Antioxidants are preservatives that prevent fats and oils in baked goods and other foods from becoming rancid or developing an off-flavor. They also prevent cut fresh fruits such as apples from turning brown when exposed to air.

- **To Provide Leavening or Control Acidity/Alkalinity.** Leavening agents, which release acids when heated, can react with baking soda to help cakes, biscuits, and other baked goods to rise during baking. Other additives help modify the acidity and alkalinity of foods for proper flavor, taste, and color.

- **To Enhance Flavor or Impart Desired Color.** Many spices and natural and synthetic flavors enhance the taste of foods. Colors, likewise, enhance the appearance of certain foods to meet consumer expectations. Examples of substances that perform each of these functions are provided in Table 1.4.

Many substances added to food may seem foreign when listed on the ingredient label, but are actually quite familiar. For example, ascorbic acid is another name for Vitamin C; alpha-tocopherol is another name for Vitamin E; and beta-carotene is a source of Vitamin A. Although there are no easy synonyms for all additives, it is helpful to remember that all food is made up of chemicals. Carbon, hydrogen, and other chemical elements provide the basic building blocks for everything in life.
1.5.4.2 What is a Food Additive?

In its broadest sense, a food additive is any substance added to food. Legally, the term refers to “any substance the intended use which results or may reasonably be expected to result, directly or indirectly, in its becoming a component or otherwise affecting the characteristics of any food.” This definition includes any substance used in the production, processing, treatment, packaging, transportation, or storage of food.

Direct Additive. If a substance is added to a food for a specific purpose in that food, it is referred to as a direct additive. For example, the low-calorie sweetener aspartame, which is used in beverages, puddings, yogurt, chewing gum, and other foods, is considered a direct additive. Many direct additives are identified on the ingredient label of foods.

Indirect Food Additives. Indirect food additives are those that become part of the food in trace amounts due to its packaging, storage, or other handling. For instance, minute amounts of packaging substances may find their way into foods during storage. Food packaging manufacturers must prove to the FDA that all materials coming in contact with food are safe, before they are permitted for use in such a manner.

### TABLE 1.4 Common Uses of Food Additives in Food Categories.

<table>
<thead>
<tr>
<th>Common Uses of Additives and Examples*</th>
<th>Foods Where Likely Used</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Impart/Maintain Desired Consistency</strong></td>
<td></td>
</tr>
<tr>
<td>Alginates, lecithin, mono- and diglycerides, methyl-cellulose, carrageenan, glyceride, pectin, guar gum, sodium aluminosilicate</td>
<td>Baked goods, cake mixes, salad dressings, ice-cream, process cheese, coconut, table salt</td>
</tr>
<tr>
<td><strong>Improve/Maintain Nutritive Value</strong></td>
<td></td>
</tr>
<tr>
<td>Vitamins A and D, thiamine, niacin, riboflavin, pyridoxine, folic acid, ascorbic acid, calcium carbonate, zinc oxide, iron</td>
<td>Flour, bread, biscuits, breakfast cereals, pasta, margarine, milk, iodized salt, gelatin desserts</td>
</tr>
<tr>
<td><strong>Maintain Palatability and Wholesomeness</strong></td>
<td></td>
</tr>
<tr>
<td>Propionic acid and its salts, ascorbic acid, butylated hydroxy anisole (BHA), butylated hydroxytoluene (BHT), benzoates, sodium nitrite, citric acid</td>
<td>Bread, cheese, crackers, frozen and dried fruit, margarine, lard, potato chips, cake mixes, meat</td>
</tr>
<tr>
<td><strong>Produce Light Texture; Control Acidity/Alkalinity</strong></td>
<td></td>
</tr>
<tr>
<td>Yeast, sodium bicarbonate, citric acid, fumaric acid, phosphoric acid, lactic acid, tartrates</td>
<td>Cakes, cookies, quick breads, crackers, butter, chocolates, soft drinks</td>
</tr>
<tr>
<td><strong>Enhance Flavor or Impart Desired Color</strong></td>
<td></td>
</tr>
<tr>
<td>Cloves, ginger, fructose, aspartame, saccharin, FD&amp;C Red No.40, monosodium glutamate, caramel, annatto, limonene, turmeric</td>
<td>Spice cake, gingerbread, soft drinks, yogurt, soup, confections, baked goods, cheeses, jams, gum</td>
</tr>
</tbody>
</table>

*Includes generally recognized as safe (GRAS) and prior-sanctioned substances as well as food additives.
1.5.4.3 What is a Color Additive? A color additive is any dye, pigment, or substance that can impart color when added or applied to a food, drug, or cosmetic, or to the human body. Color additives may be used in foods, drugs, cosmetics, and certain medical devices such as contact lenses. Color additives are used in foods for many reasons, including to offset color loss due to storage or processing of foods and to correct natural variations in food color.

Colors permitted for use in foods are classified as certified or exempt from certification. Certified colors are man-made, with each batch being tested by the manufacturer and FDA to ensure that they meet strict specifications for purity. There are nine certified colors approved for use in the United States. One example is FD&C Yellow No.6, which is used in cereals, bakery goods, snack foods, and other foods.

Color additives that are exempt from certification include pigments derived from natural sources such as vegetables, minerals, or animals. For example, caramel color is produced commercially by heating sugar and other carbohydrates under strictly controlled conditions for use in sauces, gravies, soft drinks, baked goods, and other foods. Most colors exempt from certification must also meet certain legal criteria for specifications and purity.

1.5.4.4 How are Additives Regulated? Additives are not always byproducts of twentieth-century technology or modern know-how. Our ancestors used salt to preserve meats and fish, added herbs and spices to improve the flavor of foods, preserved fruit with sugar, and pickled cucumbers in a vinegar solution. Over the years, however, improvements have been made in increasing the efficiency and ensuring the safety of all additives. Today, food and color additives are more strictly regulated than at any other time in history. The basis of modern food law in the United States is the Federal Food, Drug, and Cosmetic (FD&C) Act of 1938, which gives the FDA authority over food and food ingredients and defines requirements for truthful labeling of ingredients.

The Food Additives Amendment to the FD&C Act, passed in 1958, requires FDA approval for the use of an additive prior to its inclusion in food. It also requires the manufacturer to prove an additive’s safety for the ways it will be used. The Food Additives Amendment exempted two groups of substances from the food additive regulation process. All substances that the FDA or the USDA had determined were safe for use in specific food prior to the 1958 amendment were designated as prior-sanctioned substances. Examples of prior-sanctioned substances are sodium nitrite and potassium nitrite, used to preserve cured meats. However, at present, nitrates are called color-fixing agents for cured meats, and not preservatives, according to the FDA. The second category of substances excluded from the food additive regulation process are generally recognized as safe or GRAS substances. These substances are those whose use is generally recognized by experts as safe, based on their extensive history of use in food before 1958 or based on published scientific evidence. Salt, sugar, spices, vitamins, and monosodium glutamate are classified as GRAS substances, along with several hundred other substances. Manufacturers may also request FDA to review the use of a substance to determine if it is GRAS.

Since 1958, FDA and USDA have continued to monitor all prior-sanctioned and GRAS substances in light of new scientific information. If new evidence suggests that a GRAS or prior-sanctioned substance may be unsafe, federal authorities can prohibit its use or require further studies to determine its safety.

In 1960, Congress passed similar legislation governing color additives. The Color Additives Amendments to the FD&C Act require dyes used in foods, drugs, cosmetics, and certain medical devices to be approved by FDA prior to their marketing. In contrast
to food additives, colors in use before the legislation were allowed continued use only if they underwent further testing to confirm their safety. Of the original 200 provisionally listed color additives, 90 have been listed as safe and the remainder have either been removed from use by FDA or withdrawn by industry.

Both the Food Additives and Color Additives Amendments include a provision that prohibits the approval of an additive if it is found to cause cancer in humans or animals. This clause is often referred to as the Delaney Clause, named for its Congressional sponsor, Rep. James Delaney (D-N.Y.).

Regulations known as Good Manufacturing Practices (GMP) limit the amount of food and color additives used in foods. Manufacturers use only the amount of an additive necessary to achieve the desired effect.

1.5.4.5 How are Additives Approved for Use in Foods? To market a new food or color additive, a manufacturer must first petition to FDA for its approval. Approximately 100 new food and color additives petitions are submitted to FDA annually. Most of these petitions are for indirect additives such as packaging materials.

A food or color additive petition must provide convincing evidence that the proposed additive performs as it is intended. Animal studies using large doses of the additive for long periods are often necessary to show that the substance would not cause harmful effects at expected levels of human consumption. Studies of the additive in humans also may be submitted to FDA.

In deciding whether an additive should be approved, the agency considers the composition and properties of the substance, the amount likely to be consumed, its probable long-term effects, and various safety factors. Absolute safety of any substance can never be proven. Therefore, FDA must determine if the additive is safe under the proposed conditions of use, based on the best scientific knowledge available.

If an additive is approved, FDA issues regulations that may include the types of foods in which it can be used, the maximum amounts to be used, and how it should be identified on food labels. Additives proposed for use in meat and poultry products also must receive specific authorization by USDA. Federal officials then carefully monitor the extent of Americans’ consumption of the new additive and results of any new research on its safety to assure its use continues to be within safe limits.

In addition, FDA operates an Adverse Reaction Monitoring System (ARMS) to help serve as an ongoing safety check of all additives. The system monitors and investigates all complaints by individuals or their physicians that are believed to be related to specific foods, food and color additives, or vitamin and mineral supplements. The ARMS computerized database helps officials decide whether reported adverse reactions represent a real public health hazard associated with food, so that appropriate action can be taken.

In summary, additives have been used for many years to preserve, flavor, blend, thicken, and color foods, and have played an important role in reducing serious nutritional deficiencies among Americans. Additives help assure the availability of wholesome, appetizing, and affordable foods that meet consumer demands from season to season. Today, food and color additives are more strictly regulated than at any time in history. Federal regulations require evidence that each substance is safe at its intended levels of use before it may be added to foods. All additives are subject to an ongoing safety review as scientific understanding and methods of testing continue to improve.

1.5.4.6 Additional Information About Additives. Table 1.5 provides additional information about food additives.
TABLE 1.5 Answers to Some of the Most Popular Questions About Food Additives.

<table>
<thead>
<tr>
<th>Q</th>
<th>A</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>What is the difference between “natural” and “artificial” additives?</strong></td>
<td>Some additives are manufactured from natural sources such as soybeans and corn, which provide lecithin to maintain product consistency, or beets, which provide beet powder used as food coloring. Other useful additives are not found in nature and must be man-made. Artificial additives can be produced more economically, with greater purity and more consistent quality than some of their natural counterparts. Whether an additive is natural or artificial has no bearing on its safety.</td>
</tr>
<tr>
<td><strong>Is a natural additive safer because it is chemical-free?</strong></td>
<td>No. All foods, whether picked from your garden or your supermarket shelf, are made up of chemicals. For example, the vitamin C or ascorbic acid found in an orange is identical to that produced in a laboratory. Indeed, all things in the world consist of the chemical building blocks of carbon, hydrogen, nitrogen, oxygen, and other elements. These elements are combined in various ways to produce the starches, proteins, fats, water, and vitamins found in foods.</td>
</tr>
<tr>
<td><strong>Are sulfites safe?</strong></td>
<td>Sulfites added to baked goods, condiments, snack foods, and other products are safe for most people. A small segment of the population, however, has been found to develop hives, nausea, diarrhea, shortness of breath, or even fatal shock after consuming sulfites. For that reason, in 1986 FDA banned the use of sulfites on fresh fruits and vegetables intended to be sold or served raw to consumers. Sulfites added as a preservative in all other packaged and processed foods must be listed on the product label.</td>
</tr>
<tr>
<td><strong>Does FD&amp;C Yellow No. 5 cause allergic reactions?</strong></td>
<td>FD&amp;C Yellow No. 5, or tartrazine, is used to color beverages, dessert powders, candy ice-cream, custards, and other foods. The color additive may cause hives in fewer than one out of 10,000 people. By law, whenever the color is added to foods or taken internally, it must be listed on the label. This allows the small portion of people who may be sensitive to FD&amp;C Yellow No. 5 to avoid it. Actually, any certified color added to food is required to be listed on the label.</td>
</tr>
<tr>
<td><strong>Does the low-calorie sweetener aspartame carry adverse reactions?</strong></td>
<td>There is no scientific evidence that aspartame causes adverse reactions in people. All consumer complaints related to the sweetener aspartame have been investigated as thoroughly as possible by federal authorities for more than five years, in part under FDA’s Adverse Reaction Monitoring System. In addition, scientific studies conducted during aspartame’s preapproval phase failed to show that it causes any adverse reactions in adults or children. Individuals who have concerns about possible adverse reactions to aspartame or other substances should contact their physicians.</td>
</tr>
<tr>
<td><strong>Do additives cause childhood hyperactivity?</strong></td>
<td>No. Although this theory was popularized in the 1970s, well-controlled studies conducted since that time have produced no evidence that food additives cause hyperactivity or learning disabilities in children. A Consensus Development Panel of the National Institutes of Health concluded in 1982 that there was no scientific evidence to support the claim that additives or colorings cause hyperactivity.</td>
</tr>
<tr>
<td><strong>Why are decisions sometimes changed about the safety of food ingredients?</strong></td>
<td>As absolute safety of any substance can never be proven, decisions about the safety of food ingredients are made on the best scientific evidence available. Scientific knowledge is constantly evolving. Therefore, federal officials often review earlier decisions to ensure that the safety assessment of a food substance remains up to date. Any change made in previous clearances should be recognized as an assurance that the latest and best scientific knowledge is being applied to enhance the safety of the food supply.</td>
</tr>
</tbody>
</table>
1.5.5 Fermentation

The availability of fermented foods has a long history among different cultures. Acceptability of fermented foods also differs among cultural habits. A product highly acceptable in one culture may not be so acceptable by consumers in another culture. The number of fermented food products is countless. Manufacturing processes of fermented products vary considerably due to variables such as food groups, form, and characteristics of final products, kinds of ingredients used, and cultural diversity. Fermented foods can be prepared from various products derived from dairies, grains, legumes, fruits, vegetables, muscle foods, and so on.

1.5.6 New Technologies

At present, some alternative or new technologies in food processing are available. On June 2, 2000, the U.S. FDA released a report titled “Kinetics of Microbial Inactivation for Alternative Food Processing Technologies.” This report evaluates the scientific information available on a variety of alternative food-processing technologies. The purpose of the report is to help FDA evaluate each technology’s effectiveness in reducing and inactivating pathogens of public health concern.

The information in this section has been completely derived from this report. For ease of reading, all references have been removed. Consult the original documents for unabridged data. The citation data for this document are: A report of the Institute of Food Technologists for the Food and Drug Administration of the U.S. Department of Health and Human Services, submitted March 29, 2000, revised June 2, 2000, IFT/FDA Contract No. 223-98-2333, Task Order 1, How to Quantify the Destruction Kinetics of Alternative Processing Technologies, http://www.cfsan.fda.gov/~comm/ift-pref.html.

This section will discuss briefly the following new technologies:

- Microwave and radio frequency processing,
- Ohmic and inductive heating,
- High-pressure processing,
- Pulse electric fields,
- High-voltage arc discharge,
• Pulse light technology,
• Oscillating magnetic fields,
• Ultraviolet light,
• Ultrasound, and
• Pulse X-rays.

1.5.6.1 Microwave and Radio Frequency Processing. Microwave and radio frequency heating refers to the use of electromagnetic waves of certain frequencies to generate heat in a material through two mechanisms, dielectric and ionic. Microwave and radio frequency heating for pasteurization and sterilization are preferred to conventional heating because they require less time to come up to the desired process temperature, particularly for solid and semisolid foods. Industrial microwave pasteurization and sterilization systems have been reported on and off for over 30 years, but commercial radio frequency heating systems for the purpose of food pasteurization or sterilization are not known to be in use.

For a microwave sterilization process, unlike conventional heating, the design of the equipment can dramatically influence the critical process parameters – the location and temperature of the coldest point. This uncertainty makes it more difficult to make general conclusions about processes, process deviations, and how to handle deviations. Many techniques have been tried to improve the uniformity of heating. The critical process factor when combining conventional heating and microwave or any other novel processes would most likely remain the temperature of the food at the cold point, primarily due to the complexity of the energy absorption and heat transfer processes. As the thermal effect is presumably the sole lethal mechanism, time–temperature history at the coldest location will determine the safety of the process and is a function of the composition, shape, and size of the food, the microwave frequency, and the applicator (oven) design. Time is also a factor in the sense that, as the food heats up, its microwave absorption properties can change significantly and the location of cold points can shift.

1.5.6.2 Ohmic and Inductive Heating. Ohmic heating (sometimes also referred to as Joule heating, electrical resistance heating, direct electrical resistance heating, electothermal heating, and electroconductive heating) is defined as the process of passing electric currents through foods or other materials to heat them. Ohmic heating is distinguished from other electrical heating methods either by the presence of electrodes contacting the food, frequency, or waveform.

Inductive heating is a process in which electric currents are induced within the food due to oscillating electromagnetic fields generated by electric coils. No data about microbial death kinetics under inductive heating have been published.

A large number of potential future applications exist for ohmic heating, including its use in blanching, evaporation, dehydration, fermentation, and extraction. The principal advantage claimed for ohmic heating is its ability to heat materials rapidly and uniformly, including products containing particulates. The principal mechanisms of microbial inactivation in ohmic heating are thermal. Although some evidence exists for nonthermal effects of ohmic heating, for most ohmic processes, which rely on heat, it may be unnecessary for processors to claim this effect in their process filings.
1.5.6.3 High-Pressure Processing (HPP). High-pressure processing (HPP), also described as high-hydrostatic-pressure (HHP) or ultra-high-pressure (UHP) processing, subjects liquid and solid foods, with or without packaging, to pressures between 100 and 800 MPa. Process temperature during pressure treatment can be specified from below 0°C to above 100°C. Commercial exposure times can range from a millisecond pulse to over 20 min. Chemical changes in the food generally will be a function of the process temperature and treatment time.

The HPP process acts instantaneously and uniformly throughout a mass of food independent of size, shape, and food composition. Compression will uniformly increase the temperature of foods approximately 3°C per 100 MPa. The temperature of a homogeneous food will increase uniformly due to compression. Compression of foods may shift the pH of the food as a function of imposed pressure and must be determined for each food treatment process. Water activity and pH are critical process factors in the inactivation of microbes by HPP. An increase in food temperature above room temperature and to a lesser extent a decrease below room temperature increases the inactivation rate of microorganisms during HPP treatment. Temperatures in the range of 45 to 50°C appear to increase the rate of inactivation of food pathogens and spoilage microbes. Temperatures ranging from 90 to 110°C in conjunction with pressures of 500–700 MPa have been used to inactivate spore-forming bacteria such as Clostridium botulinum. Current pressure processes include batch and semicontinuous systems, but no commercial continuous HPP systems are operating.

The critical process factors in HPP include pressure, time at pressure, time to achieve treatment pressure, decompression time, treatment temperature (including adiabatic heating), product initial temperature, vessel temperature distribution at pressure, product pH, product composition, product water activity, packaging material integrity, and concurrent processing aids. Other processing factors present in the process line before or after the pressure treatment are not included.

Because some types of spores of C. botulinum are capable of surviving even the most extreme pressures and temperatures of HPP, there is no absolute microbial indicator for sterility by HPP. For vegetative bacteria, nonpathogenic L. innocua is a useful surrogate for the foodborne pathogen L. monocytogenes. A nonpathogenic strain of Bacillus may be useful as a surrogate for HPP-resistant E. coli O157:H7 isolates.

1.5.6.4 Pulsed Electric Fields (PEF). High-intensity pulsed electric field (PEF) processing involves the application of pulses of high voltage (typically 20–80 kV/cm) to foods placed between two electrodes. The process may be applied in the form of exponentially decaying, square wave, bipolar, or oscillatory pulses and at ambient, subambient, or slightly above ambient temperatures for less than 1 s. Energy loss due to heating of foods is minimized, reducing detrimental changes in the sensory and physical properties of foods.

Some important aspects in PEF technology are the generation of high electric field intensities, the design of chambers that impart uniform treatment to foods with minimum increase in temperature, and the design of electrodes that minimize the effect of electrolysis. Although different laboratory- and pilot-scale treatment chambers have been designed and used for PEF treatment of foods, only two industrial-scale PEF systems are available. The systems (including treatment chambers and power supply equipment) need to be scaled up to commercial systems.
To date, PEF has been applied mainly to improve the quality of foods. Application of PEF is restricted to food products that can withstand high electric fields, have low electrical conductivity, and do not contain or form bubbles. The particle size of the liquid food in both static and flow treatment modes is a limitation.

Several theories have been proposed to explain microbial inactivation by PEF. The most studied are electrical breakdown and electroporation. Factors that affect microbial inactivation with PEF are process factors (electric field intensity, pulse width, treatment time and temperature, and pulse wave shapes), microbial entity factors (type, concentration, and growth stage of the microorganism), and media factors (pH, antimicrobials, and ionic compounds, conductivity, and medium ionic strength).

Although PEF has potential as a technology for food preservation, existing PEF systems and experimental conditions are diverse, and conclusions about the effects of critical process factors on pathogens of concern and kinetics of inactivation need to be further studied.

1.5.6.5 High-Voltage Arc Discharge. Arc discharge was an early application of electricity for pasteurization of fluids by applying rapid discharge voltages through an electrode gap below the surface of an aqueous suspension of microorganisms. A multitude of physical effects (intense wave) and chemical compounds (electrolysis) are generated, inactivating the microorganisms. The use of arc discharge for liquid foods may be unsuitable, largely because electrolysis and the formation of highly reactive chemicals occur during the discharge. More recent designs may show some promise for use in food preservation, although the reported results should be confirmed by independent researchers.

1.5.6.6 Pulsed Light Technology. Pulsed light is a method of food preservation that involves the use of intense and short-duration pulses of broad spectrum “white light” (ultraviolet to the near infrared region). For most applications, a few flashes applied in a fraction of a second provide a high level of microbial inactivation. This technology is applicable mainly in sterilizing or reducing the microbial population on packaging or food surfaces. Extensive independent research on the inactivation kinetics under a full spectrum of representative variables of food systems and surfaces is needed.

1.5.6.7 Oscillating Magnetic Fields. Static (SMF) and oscillating (OMF) magnetic fields have been explored for their potential to inactivate microorganisms. For SMFs, the magnetic field intensity is constant with time, but an OMF is applied in the form of constant amplitude or decaying amplitude sinusoidal waves. An OMF applied in the form of pulses reverses the charge for each pulse. The intensity of each pulse decreases with time to about 10% of the initial intensity. Preservation of foods with OMF involves sealing food in a plastic bag and subjecting it to 1 to 100 pulses in an OMF with a frequency between 5 and 500 kHz at temperatures of 0 to 50°C for a total exposure time ranging from 25 ms to 100 ms.

The effects of magnetic fields on microbial populations have produced controversial results. Consistent results concerning the efficacy of this method are needed before considering this technology for food preservation purposes.

1.5.6.8 Ultraviolet Light. There is a particular interest in using ultraviolet (UV) light to treat fruit juices, in particular apple juice and cider. Other applications include disinfection of water supplies and food contact surfaces. Ultraviolet processing involves the use of radiation from the UV region of the electromagnetic spectrum. The germicidal properties
of UV irradiation (UVC 200–280 nm) are due to DNA mutations induced by DNA absorption of the UV light. This mechanism of inactivation results in a sigmoidal curve of microbial population reduction.

To achieve microbial inactivation, the UV radiant exposure must be at least 400 J/m² in all parts of the product. Critical factors include the transmissivity of the product, the geometric configuration of the reactor, the power, wavelength, and physical arrangement of the UV source(s), the product flow profile and the radiation path length. Ultraviolet light may be used in combination with other alternative process technologies, including various powerful oxidizing agents such as ozone and hydrogen peroxide, among others.

### 1.5.6.9 Ultrasound

Ultrasound is energy generated by sound waves of 20,000 or more vibrations per second. Although ultrasound technology has a wide range of current and future applications in the food industry, including inactivation of microorganisms and enzymes, most current developments for food applications are nonmicrobial.

Data on inactivation of food microorganisms by ultrasound in the food industry are scarce, and most applications use it in combination with other preservation methods. The bactericidal effect of ultrasound is attributed to intracellular cavitations, that is, micro-mechanical shocks that disrupt cellular structural and functional components up to the point of cell lysis. The heterogeneous and protective nature of food with the inclusion of particulates and other interfering substances severely curtails the singular use of ultrasound as a preservation method. Although these limitations make the current probability of commercial development low, combination of ultrasound with other preservation processes (e.g., heat and mild pressure) appears to have the greatest potential for industrial application.

Critical processing factors are assumed to be the amplitude of the ultrasonic waves, the exposure/contact time with the microorganisms, the type of microorganism, the volume of food to be processed, the composition of the food, and the temperature of treatment.

### 1.5.6.10 Pulsed X-Rays

It is important to realize that pulsed X-ray is one form of irradiation that has been applied to the preservation of several categories of food in the United States. Electrons have a limited penetration depth of about 5 cm in food, but X-rays have significantly higher penetration depths (60–400 cm), depending upon the energy used.

Pulsed X-ray is a new alternative technology that utilizes a solid state-opening switch to generate electron beam X-ray pulses of high intensity (opening times from 30 ns down to a few nanoseconds; repetition rates up to 1000 pulses/s in burst mode operation). The specific effect of pulses in contrast to nonpulsed X-rays has yet to be investigated.

The practical application of food irradiation by X-rays in conjunction with existing food processing equipment is further facilitated by (1) the possibility of controlling the direction of the electrically produced radiation; (2) the possibility of shaping the geometry of the radiation field to accommodate different package sizes; and (3) its high reproducibility and versatility.

Potentially, the negative effects of irradiation on food quality can be reduced.

### 1.6 Packaging

The obvious reason for packaging a food product is to protect the food so its elements will not be exposed until it is ready to be prepared and consumed. In the world of food
manufacturing, this is not a small matter, because the FDA has rigid control over the materials used in food packaging. As far as the FDA is concerned, any packaging material is considered a food additive. All packaging materials used to contain food must comply with rigid regulations for the use of a food additive. The term “food additive” means any substance the intended use of which results or may reasonably be expected to result, directly or indirectly, in its becoming a component or otherwise affecting the characteristics of any food (including any substance intended for use in producing, manufacturing, packing, processing, preparing, treating, packaging, transporting, or holding food; if such substance is not generally recognized as safe). Recently, the FDA has established the Food Contact Notification Program. It issues administrative guidance and regulations for the use of packaging materials, among others. FDA’s website (www.FDA.gov) provides details for this program.

Different materials are used as packaging containers, including, but not limited to

- Glass,
- Plastic,
- Laminates (paper-based), and
- Metal can.

Most chapters in this book contain a section on food packaging.

GENERAL REFERENCES

SPECIFIC REFERENCES