# 17 Food Processing, Packaging, and Preparation

## FOOD PROCESSING

Ever since humans first controlled fire, they have used its heat to cook some of their foods. Cooking, either by roasting, baking, steaming, frying, broiling, or boiling, makes many foods more palatable. Indeed, cooking enhances the flavor of foods such as meat; it also improves the flavor and consistency of many cereals and makes their carbohydrate content more digestible. Although not all vegetables are cooked before eating, the heating process if carefully done makes them more tender and yet preserves their natural colors and flavors. Certainly, cooking enables humans to have a wider variety of food on the dinner table. However, it can cause destruction of vitamin C, thiamine, and solubility losses of valuable minerals, especially if large amounts of water are used.

Heating has an even more important function than merely enhancing palatability characteristics. Heating food to 100°C or higher destroys harmful microbes, parasites, and some toxins that may be natural contaminants of food. *Staphylococcus* and *Salmonella* are destroyed by boiling, whereas *Clostridium botulinum* must be exposed to temperatures of 116°C (attained under pressure) if heat-resistant spores are to be eliminated. Another example is *Trichinella,* a small helminth (parasitic worm) found in uncooked pork. If consumed by humans, the worms migrate to human flesh, causing serious illness. But when pork is cooked to at least 58.5°C, the parasites are killed. Numerous harmful protozoans and worm parasites come from uncooked vegetables and fruits grown in gardens fertilized with human excreta. Although it is logical to associate such problems with primitive agriculture, they remain of concern in areas where organic gardening is not carefully practiced.

Except for grains and sugars, most foods humans eat are perishable. They deteriorate in palatability, spoil, or become unwholesome when stored for long periods. Surplus animal and crop harvests, however, can be saved for future use if appropriate methods of preservation are used. The major ways of preserving foods are canning, freezing, drying, salting, and smoking. With all methods the aim is to kill or restrict the growth of harmful microbes or their toxins and to slow or inactivate enzymes that cause undesirable changes in food palatability. For further protection during long periods of storage, preserved food is placed either in sterile metal cans or glass jars or frozen in airtight paper or plastic containers.

In many parts of the world, people continue to raise and preserve a large portion of their own food for use throughout the year, but in the West people rely heavily on fresh and commercially processed foods purchased in nearby supermarkets.

## CANNING

Ever since Louis Pasteur proved that microbes, invisible to the eye, caused food to putrefy, various methods have been used to kill these harmful organisms. The basic process in canning is to heat the food to boiling point or higher under pressure, then pack and completely seal it in sterilized containers. The precise processing temperatures and times are dependent upon the acidity of the particular foodstuffs being processed. Foods with a slightly acidic pH (4.5 and higher) require the high heat of pressure canners to ensure safe processing. The density of the foodstuffs as well as the size and shape of the container also influence processing times.

The average energy input in commercial canning of vegetables and fruits is about 575 kcal/kg of food (Table 17.1). This figure represents only the energy expended in actual processing by heat and does not include the energy input required for making the container. (Packaging is discussed later in this chapter.) Canning vegetables in the home is much more energy intensive than commercial processing. For example, home-canned beans require 757 kcal/kg (Klippstein, 1979).

**TABLE 17.1**
**Energy Inputs for Processing Various Products**

| Product | kcal/kg | Remarks |
|---|---|---|
| Beet sugar | 5,660 | Assumed 17% sugar in beets |
| Cane sugar | 3,370 | Assumed 20% sugar in cane |
| Fruit and vegetables (canned) | 575 | |
| Fruit and vegetables (frozen) | 1,815 | |
| Flour | 484 | Includes blending of flour |
| Baked goods | 1,485 | |
| Breakfast cereals | 15,675 | |
| Meat | 1,206 | |
| Milk | 354 | |
| Dehydrated foods | 3,542 | |
| Fish (frozen) | 1,815 | |
| Ice cream | 880 | |
| Chocolate | 18,591 | |
| Coffee | 18,948 | Instant coffee |
| Soft drinks | 1,425 | Per liter |
| Wine, brandy, spirits | 830 | Per liter |
| Pet food | 828 | |
| Ice production | 151 | |

*Source*: After Casper, M.E., *Energy-Saving Techniques for the Food Industry*, Noyes Data Corp, Park Ridge, NJ, 1977.

## FREEZING

In freezing, many of the desirable qualities of the fresh food are retained for relatively long periods of time. The temperatures employed, −18°C or lower, retard or prevent the growth of harmful microbes. Their growth is also inhibited by lack of water, which is frozen.

Fruits can be frozen dry with added dry sugar or in syrup. Vegetables must be blanched (boiled or steamed a short time) prior to freezing to inactivate plant enzymes that cause deterioration of natural flavors and colors. The energy input for freezing vegetables and fruits is significantly greater than that for canning, averaging 1815 kcal/kg of food frozen versus only 575 kcal/kg for canning (Table 17.1). The canning process requires only heating, whereas freezing may involve brief heating, cooling, and then actual freezing.

Furthermore, canned foods can be stored at room temperature (actually slightly cooler is recommended), whereas frozen food must be kept in freezers at temperatures of −18°C or lower. Maintaining such a low temperature requires about 265 kcal/kg/month of storage (USBC, 1975). The average energy input to store frozen foods in the home freezer is 1060 kcal/kg (Klippstein, 1979). Because frozen foods are usually stored about 6 months, this additional energy cost is significant, making the total energy input much greater than that for canning. However, the moisture-resistant plastic and paper containers for frozen foods require less energy to manufacture than the metal cans and glass jars used for canned food.

## SALTING

Fish, pork, and other meats have been preserved by salting for more than 3000 years (Jensen, 1949). This food-processing method is not employed as widely today in developing countries as it has been in the past, perhaps because other methods make possible the preservation of a wider variety of foods.

Salt (NaCl) preserves fish and meat by dehydrating it and, more important, by increasing the osmotic pressure to a level that prevents the growth of microbes, insects, and other small organisms. Like sun-drying of foods in warm, sunny climates, salting requires a relatively small input of energy. Usually about 1 kg of salt is added per 4 kg of fish or meat (Hertzberg et al., 1973). The method requires an estimated 23 kcal/kg of fish or meat; additionally, 90 kcal of fossil energy is required to produce 1 kg of salt (Rawitscher and Mayer, 1977). Even so, the total energy input for salting is significantly lower than that required for freezing fish or meat.

The salted product can be stored in a cool, dry area or placed in a moisture-free container. Before the salted fish or meat can be eaten, it must be soaked and rinsed many times with fresh water to remove the salt. Then the fish or meat is usually cooked, but even after the soaking and the rinsing there is usually a sufficient residue to give the food a noticeably salty taste.

## DRYING

Reducing the moisture level of grains, meats, legumes, and fruits to 13% or lower prevents the growth of harmful microbes and lessens chances for infestations by insects and other organisms. Sunlight, an effective source of energy for drying, has been used for centuries and is still used today, especially for such crops as fruits and legumes. It has the distinct advantage of being a continuous, unlimited energy source.

When not accomplished by the slow sun-drying method, drying becomes energy intensive because the removal of water requires large inputs of heat energy. For instance, removing 1 L of water from grains requires an average energy input of 3600 kcal (Leach, 1976). However, Leach (1976) reports that by using the most efficient technology available, it is possible to remove a liter of water from grains with an input of only 1107 kcal/L.

In investigating the drying of corn in the United States, Pimentel et al. (1973) reported an energy input of 1520 kcal/L of water removed. Put another way, 1520 kcal is expended to reduce the moisture level of 7.4 kg of field-harvested corn from 26.5 to 13%.

The average energy input used to dehydrate foods is 3542 kcal/kg (Table 17.1). Thus, the energy input for drying approximately equals the food energy contained in 1 kg of many typical grains (about 3400 kcal). For potato flakes, the energy input for drying can be as high as 7517 kcal/kg (Singh, 1986).

All these calculated energy inputs for removing moisture from foods are higher than the theoretical values for evaporation. For example, the evaporation of 1 L of water from an open container theoretically requires as little as 620 kcal of energy (HCP, 1974). However, two to six times more energy is generally required to dehydrate food because the water in the food is not as accessible as it is in an open dish and must be removed from inside the cells of vegetables, fruits, or meats. In other words, barriers must be overcome to remove the water from food, and this requires extra energy.

In freeze-drying, a recently developed technique, the food is first frozen, then dried under extremely low pressure. This makes it possible to attain a moisture content much lower than 13%; the resultant food is exceptionally light and can be stored at room temperature. However, this process is even more energy intensive than regular drying because it requires energy for both freezing and drying.

## SMOKING

Smoking, like drying, originated in primitive societies yet is still used today. Fish, meats, and grains are the major foods preserved by this method. Smoking preserves food in two ways. First, the heat dries or dehydrates the food; second, the various tars, phenols, and other chemicals in the smoke are toxic to microbes and insects. Most of these chemicals are also carcinogenic to humans if consumed in large amounts.

In many developing countries, farm families hang grains from the ceiling of the kitchen, where the smoke and heat from the open fire both dry and smoke the stored grain. This simple processing and storage method minimizes insect and microbial growth.

To smoke 1 kg of thin strips of fish, about 1 kg of hardwood (such as hickory) is used. Adding sand to the hardwood chips keeps the fire smoldering during the smoking process. The energy input for smoked fish is estimated to be about 4500 kcal/kg, with all of the energy coming from the wood chips burned.

## VARIOUS PROCESSED AND PREPARED FOODS

The energy inputs for preserved, processed, and home-prepared foods are substantial. For example, in an analysis of the energy inputs needed to produce a 1-kg loaf of white bread commercially in the United Kingdom, Leach (1976) reported that 77% of the 3795 kcal total energy used to produce the bread (including marketing costs) is used in processing, with 13% for milling and 64% for baking.

In the United States, producing a 1-kg loaf of white bread requires an input of 7345 kcal, substantially greater than that for the United Kingdom. Milling and baking account for only 27% of the total energy input, as compared with 77% in Leach's analysis (Figure 17.1). Of the 27%, 7% of the energy is for milling and 20% for baking, which is appreciably lower than the input for wheat production, and which in turn is 45% of the total energy input. Hence, the major energy input for the white bread produced in the United States is expended for wheat grain production, and it would appear that energy inputs for grain production for bread is appreciably lower than in the United States (Figure 17.1).

The energy inputs to produce a 455-g can of sweet corn differ greatly from those expended for a loaf of white bread. The energy for production of the corn itself amounts to little more than 10% of the total energy used (Figure 17.2). Most of the total energy input of 1322 kcal is for processing, in particular for the production of the steel can. The heat processing of the corn requires only 316 kcal, but the production of the can requires about 1006 kcal.

The other large input that must be included in the energy accounting for processed foods is the energy expended by the consumer shopping for the food. In the United States, food shopping usually requires the use of a 1000- to 3000-kg automobile. Based on an allocation of the weight of the corn and other groceries, it takes about 311 kcal—or about three-fourths the amount of energy expended to produce the corn

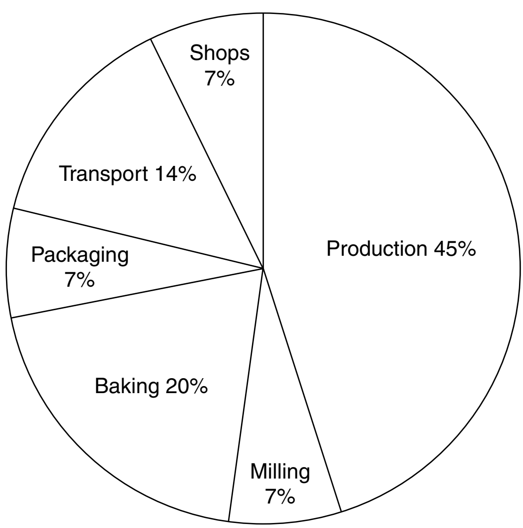


**FIGURE 17.1** Percentages of total inputs (7345 kcal) for the production, milling, baking, transport, and shopping for a 1-kg loaf of bread.

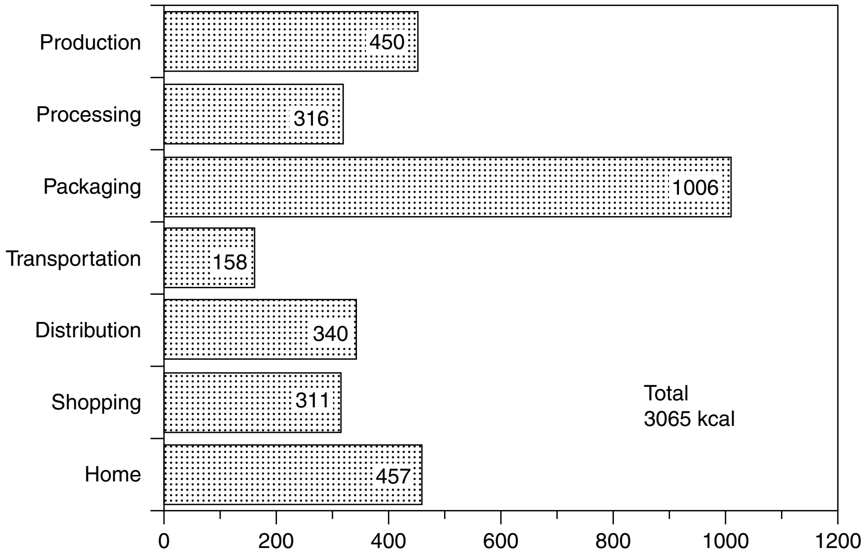


**FIGURE 17.2** Energy inputs for a 455-g (375-kcal) can of sweet corn.

itself—to transport a 455-g can of corn home from the store. Energy expended in home preparation amounts to 457 kcal, or 12% of the total, and includes cooking the corn and using an electric dishwasher to clean the pots, pans, plates, and other utensils used.

All the energy inputs for producing, processing, packaging, transporting, and preparing a 455-g can of corn total 3065 kcal (Figure 17.2). Contrast that with the 375 kcal of food energy provided by the corn. Hence, about 9 kcal of fossil energy is necessary to supply 1 kcal of sweet corn food energy at the dinner table.

The pattern of energy inputs for beef differs greatly from that for sweet corn. Although 140 g of beef provides about 375 kcal of food energy, about 1000 kcal of fossil energy are expended just in the production of this amount of beef. The energy inputs for beef, including those for processing, transportation, and marketing, are all relatively small compared to the production inputs. The prime reason for the high production input is that large quantities of grain are fed to beef animals in the United States. Energy accounting of the U.S. food system is complicated by the fact that most of the corn and other cereal grains suitable for human consumption are fed to livestock.

The energy inputs for processing several other food products are presented in Table 17.1. The relatively large inputs for processing of 1 kg of sugar—3370 kcal for cane sugar and 5660 kcal for beet sugar—are due primarily to the energy used for the removal of water by evaporation, an energy-intensive process. Thus, 1 kg of crystalline sugar, which has a food energy value of 3850 kcal, requires almost that much energy to process the cane.

Breakfast cereals also require much energy to process and prepare—on the average, about 15,675 kcal/kg (Table 17.1). One kilogram of cereal contains about

3600 kcal of food energy. The energy inputs include those required for grinding, milling, wetting, drying, and baking the cereals. Other technologies such as extrusion are sometimes used, and these require additional large inputs of energy.

Both chocolate and coffee concentrates require energy-intensive food-processing techniques, including roasting, grinding, wetting, and drying. Processing of 1 kg of chocolate or coffee requires more than 18,000 kcal/kg (Table 17.1).

The energy inputs for soft-drink processing are high because of the pressurized systems employed to incorporate carbon dioxide (Table 17.1). A total of 1425 kcal is required per liter of soft drink produced. By way of comparison, the processing of milk requires only 354 kcal/L. A 12-ounce can of diet soda requires about 600 kcal for the soda but 1600 kcal for the aluminum can. Thus, a can of diet soda with 1 kcal of food energy requires a total of 2200 kcal of fossil energy to produce.

## PACKAGES FOR FOODS

In general, processed foods must be stored in some type of container. For instance, 455 g of frozen vegetables are usually placed in a small paper box that requires an expenditure of approximately 722 kcal of energy to make (Table 17.2). By contrast, the same quantity (455 g) of a canned vegetable such as corn is placed in a steel can

**TABLE 17.2**
**Energy Required to Produce Various Food Packages**

| Package | kcal |
|---|---|
| Wooden berry basket | 69 |
| Styrofoam tray (size 6) | 215 |
| Molded paper tray (size 6) | 384 |
| Polyethylene pouch (16 oz or 455 g) | 559[a] |
| Steel can, aluminum top (12 oz) | 568 |
| Small paper set-up box | 722 |
| Steel can, steel top (16 oz) | 1006 |
| Glass jar (16 oz) | 1023 |
| Coca-Cola bottle, nonreturnable (16 oz) | 1471 |
| Aluminum TV dinner container | 1496 |
| Aluminum can, pop-top (12 oz) | 1643 |
| Plastic milk container, disposable (0.5 gallon) | 2159 |
| Coca-Cola bottle, returnable (16 oz) | 2451 |
| Polyethylene bottle (1 qt) | 2494 |
| Polypropylene bottle (1 qt) | 2752 |
| Glass milk container, returnable (0.5 gallon) | 4455 |

[a] Calculated from data of Berry and Makino.

*Source*: After Berry, R.S. and Makino, H., *Technology Review*, 76, 1–13, 32–43, 1974.

that requires 1006 kcal to make (Table 17.2). The energy input for a glass jar for 455 g of vegetables is 1023 kcal, about the same as that used to produce a steel can (Table 17.2).

Thus, processing 455 g of corn and placing it into a steel can requires an input of about 1300 kcal of energy (Figure 17.2). About 1550 kcal is expended in freezing 455 g of corn and placing it in a cardboard box, and the food must be stored at 0°C or lower, requiring an energy expenditure of about 265 kcal/kg/month.

Although there is little difference between the energy inputs required for the production of steel cans and glass jars, aluminum soft-drink cans require significantly higher energy inputs. A 355-milliliter (ml) steel can for soft drinks requires an input of about 570 kcal; the same size aluminum can requires 1643 kcal, nearly three times as much energy (Table 17.2). A 355-ml aluminum can of soda contains about 150 kcal of food energy in the form of sugar, equivalent to about 10% of the energy expended in the production of the aluminum can.

Aluminum food trays commonly used to hold frozen TV dinners also require a large energy input. An average tray requires 1500 kcal to make (Table 17.2), often more energy than the food the tray holds (usually 800–1000 kcal). In addition, the diverse containers used to display fruits, vegetables, and meats in grocery stores require energy for production. Energy expenditures range from about 70 kcal for wood berry baskets to 380 kcal for molded paper trays (Table 17.2).

Because of increased concern about solid waste, the energy inputs of recycling milk and beverage bottles have been analyzed. A disposable plastic half-gallon milk container requires 2160 kcal for production, whereas a half-gallon glass container requires 4445 kcal (Table 17.2). The returnable glass container must be used at least twice for an energy saving to be realized. Actually, because added energy is expended to collect, transport, sort, and clean the reusable container, it takes about four recycles of each glass container to gain an advantage over disposable containers.

Like milk containers, returnable glass beverage bottles require more energy for production than do nonreturnable bottles (Table 17.2). A 16-ounce returnable soft-drink bottle requires about 2450 kcal for production, compared to about 1470 kcal for the same size nonreturnable bottle. Although two uses of the returnable bottle would more than offset the production energy input, when the energy costs of collecting, transporting, and cleaning the returnable bottles are factored in, about four recycles are necessary to gain an energy advantage. Of course, other considerations, such as the costs and the environmental pollution caused by nonreturnable containers, must be weighed along with energy expenditure before community policies can be decided upon.

## COOKING AND PREPARING FOODS

Foods for human consumption are often cooked or reheated in the home, requiring an expenditure of energy. In the United States, an estimated 9000 kcal of fossil energy are used per person per day for home refrigeration, heating of food, dishwashing, and so forth. This averages out to an estimated 4700 kcal/kg of food prepared.

Depending on the food, the fuel used, the material of the cooking containers, the method of preparation, and the stove used, the energy input varies considerably. There appears to be little difference between the total energy expended for baking, boiling, or broiling a similar product, assuming that that exposure of the food to heat is optimal and that the cooking utensils allow for efficient heat transfer to the food itself. In addition to the shape and construction material of the cooking utensils, color also affects the transfer of heat and, therefore, overall cooking efficiency. A shiny aluminum pan reflects much heat and therefore is less efficient than one with a dark, dull surface or one made from glass. Furthermore, the nature of the food itself—fluid, viscous, or dense—will either slow or speed heat transfer and alter the amount of energy used in a particular process. These variables make it difficult to calculate the precise energy expenditure.

When the efficiency of the entire cycle of energy transfer is compared, a gas stove is more efficient than an electric stove. Gas and electricity from coal are used as fuel in residential stoves. Gas is mined, and about 10% of its energy potential is lost in production and transport. In transferring its heat energy to a product, it is 37% efficient, making overall efficiency of cooking with gas about 33% ($100 \times 0.9 \times 0.37$).

The process for electricity is more complicated than for gas. First, mining and transport reduce the energy potential of coal by 8%; 92% of the initial energy potential of the coal is available at the power plant for generation of electricity. Coal-heat conversion into electricity results in a recovery of 33% of the energy potential. The transmission electricity over power lines is 92% efficient, and transmission of electric heat to the product is 75% efficient. Thus, the overall efficiency of heat to the product is about 21% ($100 \times 0.92 \times 0.33 \times 0.92 \times 0.75$).

Less efficient than either electricity or gas is cooking with charcoal or wood over an open hearth, as is often done in developing countries. An open fire is 8–10% efficient in transmitting heat to the food. However, if the wood fire is carefully tended under the pot, the transfer of energy can be nearly 20%, which is nearly as efficient as using a small wood stove, which is from 20 to 25% efficient.

The following examples demonstrate the general inefficiency of cooking food over an open wood fire. It takes 600 kcal of heat energy to cook 1 kg of food, so a wood fire, at an efficiency rate of 10% for cooking, must produce 6000 kcal of energy. The food itself, if a grain-like rice, would contain 3500 kcal of food energy. Hence, nearly twice as much energy would be used to cook the food than the food itself contains.

In developing nations, cooking uses nearly two-thirds of the total energy expended in the food system and production the remaining one-third (Table 17.3). Almost all of the energy used for cooking in developing countries comes from renewable sources, primarily biomass (wood, crop residues, and dung).

A significant percentage of wood is converted into charcoal for a cooking fuel. Like wood fires, open charcoal fires are about 10% efficient in the transfer of heat energy to food. However, charcoal production is extremely energy intensive. Although charcoal apparently has a high energy content (7100 kcal/kg), 28,400 kcal of hardwood must be processed to obtain the 7100 kcal of charcoal, a conversion efficiency of only 25%. Therefore, charcoal heating has an overall energy transfer efficiency of

**TABLE 17.3**
**Model of Annual per Capita Use of Energy in the Food System of Rural Populations in Developing Countries**

| | Fossil energy (kcal) | Renewable energy (kcal) | Total (kcal) |
|---|---|---|---|
| Production of food | 130,000 | 490,000 | 620,000 |
| Processing | 15,000 | 20,000 | 35,000 |
| Storage | 5000 | 20,000 | 25,000 |
| Transport | 30,000 | 20,000 | 50,000 |
| Preparation | 20,000 | 1,250,000 | 1,270,000 |
| Total | 200,000 | 1,800,000 | 2,000,000 |

*Sources*: Pimentel, D., *Environmental Biology*, 74(1), 1974 and In *Enciclopedia della Scienza e della Tecnica*, Mondadori, Milan, 1976, 251–266; Pimentel, D. and Beyer, N., unpublished data at Cornell University, Ithaca, NY, 1976; RSAS, presented at Energy Conference, Aspenasgarden, October 27–31. Stockholm, Sweden, Royal Swedish Academy of Sciences 1975; Revelle, R., personal communication, University of California at San Diego, La Jolla, CA, 1986; and Ernst, E., *Fuel Consumption Among Rural Families in Upper Volta*, Upper Volta, Eighth World Forestry Congress, 1978.

only 2.5% (25% × 10%). Not only is cooking with charcoal an extremely inefficient and costly way to transfer energy, the use of charcoal for fuel also depletes forest and firewood supplies (Eckholm, 1976).

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