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Processing of Horticultural Crops

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PRINCIPLES OF HORTICULTURAL CROP PRESERVATION

Food production in the United States, which includes the agricultural sector, food processing, and marketing operations and all the related support industries, generates about 20% of the gross national product and utilizes approximately 25% of the total U.S. work force. If one considers the activities of food production, manufacturing, marketing, restaurants, and institutions combined, the food industry is easily the largest industrial enterprise in the United States (Potter and Hotchkiss 1995). This chapter will highlight the principles of horticultural crop preservation, the importance of raw material quality, unit operations common to most types of processing, and specific technologies applicable to the processing of horticultural crops. Finally, the advantages and disadvantages of the various available technologies will be discussed, followed by general comments on packaging and quality control.

WHY PROCESS?

Ideally, most consumers would like to obtain and consume fruits and vegetables when they are the freshest, that is, when their color, texture, flavor and nutritional value are optimal. Unfortunately, most of us do not have the ability to maintain gardens or greenhouses that would supply us year-round with the variety of horticultural products that we desire. In addition, many fruits and vegetables are only produced in certain growing regions, for example, pineapple, papayas, blueberries, sweet corn, and artichokes. Some horticultural products are only produced during a very short window of time, and once that passes fresh products are no longer available. For these reasons and those listed below, processing and later consumption of horticultural products is often a desirable alternative to fresh consumption. Processing serves to

- extend seasonality
- allow consumption in regions distant from the growing region
- prolong shelf life and arrest deterioration during storage
- improve the nutritional quality and digestibility of some foods
- enhance the microbiological and chemical safety of food
- allow for long-term storage in case of drought or famine
- increase the variety and desirability of food (add value)
- improve quality control and provide a more consistent product
- permit extraction of key nutrients for health or medicinal uses
- enhance convenience and reduce preparation time prior to consumption
- in some cases, reduce cost of fresh horticultural product

MAJOR CAUSES OF FOOD DETERIORATION

Horticultural crops naturally mature and ripen, then begin the processes of senescence and deterioration. Over time, undesirable changes in color, texture, aroma and flavor, nutritional value, and safety may render fresh fruits and vegetables unacceptable for consumption. These changes are caused by physical, chemical, and biological factors that include (Potter and Hotchkiss 1995):

- survival and growth of bacteria, yeasts and molds
- chemical reactions, including those catalyzed by enzymes
- insect, parasite, and rodent infestation
- poor control of temperature
- loss or gain of moisture
- reactions with O_2
- reactions with light
- physical abuse or stress
- time

In most cases these factors do not act in isolation; depending on the commodity and environmental conditions, they may act in concert to increase the rate of horticultural crop deterioration. Because of the number of deteriorative factors and the diverse nature of fruit and vegetable crops, many different types of preservation technologies are utilized to prevent deterioration.

PRINCIPLES OF FOOD PRESERVATION

Food preservation may be targeted to either the short or long term. Short-term preservation is applicable to horticultural commodities that are consumed relatively soon after harvest. For them, the best preservation technique involves keeping the product alive and respiring. The fresh-cut horticultural product industry operates along this principle, and prepared salads, carrots, broccoli, cauliflower, and melon products are stored under refrigerated MA conditions that maintain metabolism. If it is not possible to maintain horticultural products in a live state, short-term preservation will be enhanced if the commodity is cleaned, covered, and cooled as quickly as possible. Short-term preservation does not involve destruction of microorganisms or enzymes; deteriorative reactions will therefore proceed, often at a faster rate due to the stresses imparted during harvesting and handling operations.

This chapter focuses primarily on long-term preservation, which normally encompasses inactivation or control of microorganisms and enzymes and reduction or elimination of chemical reactions that cause food deterioration. Microorganisms may be controlled through the use of heat, cold, dehydration, acid, sugar, salt, smoke, atmospheric composition, and radiation (Potter and Hotchkiss 1995). Mild heat treatments in the range of 82° to 93°C (180° to 200°F) are commonly used to kill bacteria in low-acid foods (pH ≥4.6), but to ensure spore destruction, temperatures of 121°C (250°F) wet heat for 15 minutes or longer are required. High-acid foods (pH <4.6) require less heat, and often a treatment of 93°C (200°F) for 15 minutes will ensure commercial sterility. If the water activity (a_w), or water available for microbial growth, is 0.85 or below, no thermal process is required regardless of pH. Design of the thermal process that will ensure the safety of a specific product is best carried out by "process authorities," individuals with experience and knowledge of bacteriology and thermal process design.

Refrigeration and freezing slow microbial growth and may kill a small fraction of microorganisms present in or on a fruit or vegetable, but they do not kill all bacteria. If all of the water in a product exists in a solid state, growth of microorganisms will be prevented, but growth will resume at the same or perhaps at an even more rapid rate when thawed. Dehydration serves to remove water required for growth from microbial cells and preserve horticultural crops against microbial deterioration. In a similar fashion, sugar and salt act as preservatives because they cause osmotic dehydration of microbial cells and eventual death. Control of moisture or RH of storage environments is an important consideration in terms of desired maintenance of horticultural crop life and undesired preservation of microorganisms.

Natural fruit and vegetable acids reduce the severity of thermal treatment required because acids denature bacterial proteins and may result in cell death. Atmospheric composition is often utilized in storage and packaging of horticultural products to prevent deterioration. Oxygen is a prerequisite for not only many microbial but also chemical deterioration reactions; therefore, replacement with either nitrogen or carbon dioxide may be beneficial. Finally, microorganisms are inactivated to various degrees by X-rays, microwaves, ultraviolet light, and ionizing and other forms of radiation.

SHELF LIFE DATING

Shelf life is generally defined as the time it

takes for a product to become unacceptable for consumption or unsalable. Unacceptability may be determined by the processor, the retailer, or the consumer and may be the subject of controversy. Quantification of shelf life depends on measurement of sensory, instrumental, or microbial deterioration, and the rate is affected by the type of product, processing method, packaging, and storage conditions. Many processors use code dates that include the "pack date," "display date," "sell by date," "best used by date," or "expiration date" (Potter and Hotchkiss 1995).

RAW MATERIAL QUALITY

Earlier chapters in this book were devoted to a discussion of fruit and vegetable maturity (chapter 6) and quality (chapters 22 and 23) factors specific to crops destined for fresh consumption. Although in many cases these same factors may be required of horticultural crops destined for processing, this is not always true. Standards of raw material quality for processed products may be less stringent because the fruit or vegetable may ultimately be peeled, sliced, pureed, or even juiced. Factors important to raw material quality are discussed below.

VARIETY SELECTION

The selection of horticultural varieties for the specific purpose of processing is somewhat different from selection strictly for the fresh market. Varieties destined for processing may be exposed to mechanical harvesting, rigorous cleaning and peeling operations, size reduction operations, and high- or low-temperature preservation methods. Different varieties of the same commodity may deviate in, for example, the ease with which peels are removed, the textural integrity after thermal processing, the color stability during drying, the flavor retention during frozen storage, or the nutritional value after irradiation. Some varieties may be best targeted for one specific processed product rather than another. For example, one tomato variety may be an excellent raw material for ketchup products because of its color and flavor, yet this same variety may be a poor raw material for diced tomato products because of poor textural integrity. It is important to evaluate not only the raw product but also the intended processed product when selecting processing varieties. Many large processors of horticultural products provide seed to growers with whom they contract.

MATURITY

Desired harvest maturity depends on a number of factors, including the variety, growing region, weather conditions, soil type, ease of harvest, hand versus mechanical harvest, and final processed product. Fruits generally increase in both sugar and acid content as they mature, but other factors such as textural integrity and appearance may decline with maturity. If the fruit is intended for juice processing, where texture and appearance are of little significance, harvesting should be carried out when the fruit is fully ripe. If textural integrity and appearance are important, for example, in the case of a "fruit half" or sliced product, the fruit might be harvested at an earlier maturity stage. Vegetables differ from fruits in that they often become tougher and more lignified as they mature, and this may adversely affect the ease of processing, flavor, and texture of the processed product. In addition, the starch content may increase in some seed and many root and tuber crops, and this may be either desirable or undesirable in the processed vegetable. Determination of optimal harvest maturity is not always straightforward, and many factors other than quality may affect this decision.

QUALITY SPECIFICATIONS

Quality standards or specifications for processed horticultural products may be set by the federal or state government, trade organizations, or by private companies. Government standards may be mandatory when they deal with the protection of consumer health and prevention of consumer deception. Other government standards such as the U.S. Grade Standards are voluntary and are aimed at helping producers, brokers, wholesalers, processors, retailers, and consumers in the marketing of processed food products.

Examples of voluntary standards are the USDA Standards for Processed Fruit and Vegetable Products, which were put in place to identify the degree of quality in a product and thereby assist in establishing usability or value. Fresh fruit, nut, and vegetable grade standards were established in 1917, and

Table 37.1. Relative importance of factors involved in USDA standards for processed fruit and vegetable products

Product	Absence of defects	Color	Flavor	Character	Consistency	Uniformity	Texture	Tenderness and maturity	Clearness of liquor
Apples	20	20	—	40	—	20 size	—	—	—
Apple butter	20	20	20	20 finish	20	—	—	—	—
Apple juice	20	20	60	—	—	—	—	—	—
Apple sauce	20	20	20	20 finish	20	—	—	—	—
Apricots	30	20	—	30	—	20 size	—	—	—
Asparagus	30	20	—	—	—	—	—	40	10
Beans, green and wax	35	15	—	—	—	—	—	40	10
Beans, dried	40	—	—	40	20	—	—	—	—
Beans, lima	25	35	—	30	—	—	—	—	10
Beets	30	25	—	—	—	15	30	—	—
Berries	30	20	—	30	—	20	—	—	—
Blueberries	40	20	—	40	—	—	—	—	—
Carrots	30	25	—	—	shape	15 size	30	—	—
Cherries, sweet	30	30	—	20	—	20 size	—	—	—
Cherries, sour	30	20	—	30	—	20 pits	—	—	—
Chili sauce	20	20	20	20	20	—	—	—	—
Corn, cream	20	10	20	—	20	—	—	30	—
Corn, whole	20	10	20	—	—	—	—	40	10
Cranberry sauce	20	20	20	—	40	—	—	—	—
Figs, kadota	30	20	—	35	—	15 size	—	—	—
Frozen apples	20	20	—	40	—	20	—	—	—
Fruit cocktail	20	20	—	20	—	20	—	—	20
Fruit jelly	—	20	40	—	40	—	—	—	—
Fruit preserv. (jam)	20	20	40	—	20	—	—	—	—
Fruit salad	30	20	—	30	—	20 size	—	—	—
Grapefruit	20	20	—	20	—	(Wholeness, 20)	(Drained wt., 20)		
Grapefruit juice	40	20	40	—	—	—	—	—	—
Grape juice	20	40	40	—	—	—	—	—	—
Lemon juice	35	35	30	—	—	—	—	—	—

standards for canned, frozen, and dried fruit and vegetables, and other related products such as preserves were created in 1928. Grading is typically based on a scoring system for four quality factors: color, size uniformity, absence of defects, and character (maturity, texture, and tenderness). The relative importance of various factors to specific processed horticultural crops was itemized by Kramer and Twigg (1970) and is illustrated in table 37.1. Definitions of each factor are included with the standard for that particular commodity.

Trade organizations are generally established by the members of a particular industry on a voluntary basis to assure at least minimum acceptable quality and to prevent a lowering of quality standards. Company standards for quality often go beyond the minimum quality standards suggested by the government.

UNIT OPERATIONS

Because the number and type of processing technologies applied to fruit and vegetable products is immense and diverse, food scientists attempt to organize them into the common "unit" operations that comprise them (see fig. 37.1). For example, heating or thermal processing is common to the manufacture of orange juice, strawberry-kiwi jam, canned peaches, french fried potatoes, cucumber pickles, and sun-dried tomatoes. Some processing systems are composed of very few unit operations, while other systems include a multitude of operations. In order to successfully preserve fruit and vegetable products it is essential to select and combine the most appropriate unit operations into more complex processing systems. A number of the unit operations most commonly used in

Table 37.1. Cont.

Product	Absence of defects	Color	Flavor	Character	Consistency	Uniformity	Texture	Tenderness and maturity	Clearness of liquor
Mushroom	30	30	—	20	—	20 size	—	—	—
Olives, green	30	30	—	20	—	20 size	—	—	—
Olives, ripe	10	15	30	25	—	20	—	—	—
Orange juice	20	40	40	—	—	—	—	—	—
Orange juice concen.	20	40	40	—	—	—	—	—	—
Orange marmalade	20	20	40	—	20	—	—	—	—
Okra	20	15	15	—	—	10	—	35	5
Peaches	30	20	—	30	—	20 size	—	—	—
Peanut butter	30	20	30	—	20	—	—	—	—
Pears	30	20	—	30	—	20 size	—	—	—
Peas	30	10	—	—	—	—	—	50	10
Peas, field	40	20	—	40	—	—	—	—	—
Cucumber, pickled	30	20	—	—	—	20	30	—	—
Pimientos	40	30	—	10	—	20 size	—	—	—
Pineapples	30	20	—	30	—	20	—	—	—
Pineapple juice	40	20	40	—	—	—	—	—	—
Plums	30	20	—	30	—	20 size	—	—	—
Potatoes, peeled	40	20	—	—	—	20	20	—	—
Prunes, dried	30	20	—	35	—	15	—	—	—
Pumpkins and squash	30	20	—	20 finish	30	—	—	—	—
Raspberries	20	25	—	35	—	20 size	—	—	—
Sauerkraut	10	15	45	15 crisp	—	—	—	—	15
Sauerkraut, bulk	10	15	45	15 crisp	—	—	—	—	15
Spinach	40	30	—	30	—	—	—	—	—
Sweet potatoes	40	20	—	20	—	20 size	—	—	—
Tomatoes	30	30	—	—	—	(Wholeness, 20)	(Drained wt., 20)		
Tomato juice	15	30	40	—	15	—	—	—	—
Tomato paste	40	60	—	—	—	—	—	—	—
Tomato pulp, puree	50	50	—	—	—	—	—	—	—
Tomato sauce/catsup	25	25	25	—	25	—	—	—	—

Source: Kramer and Twigg 1970.

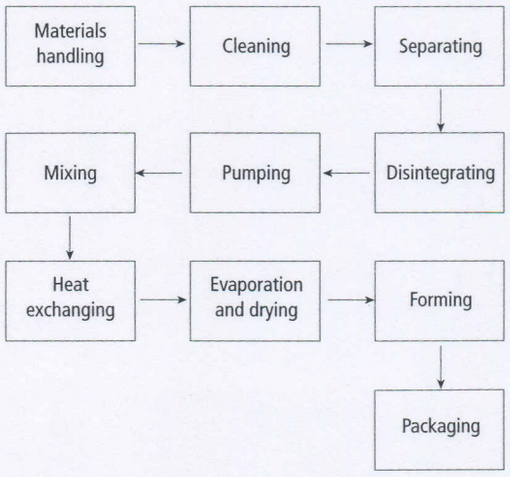
horticultural product processing are described below.

MATERIALS HANDLING

Materials handling operations encompass those that move horticultural crops from the farm to the packinghouse or processing plant and subsequently through the various unit operations in the plant. Included are hand and mechanical harvesting, refrigerated trucking, container transportation, and conveying of fruits and vegetables through the processing system. Throughout all materials handling operations it is essential to maintain sanitary conditions, minimize product loss (quantitative and qualitative), maintain raw material quality, minimize microbial contamination and growth, and schedule transfers and deliveries so that process delays are minimized.

Figure 37.1

Unit operations in horticultural crop processing.



CLEANING AND SANITIZING

Cleaning and sanitizing of food materials and processing equipment surfaces is important to ensure that safe products are produced. However, fruits and vegetables that are peeled are seldom washed before peeling. Cleaning may range from simple removal of soil and other foreign matter on pome fruits by dumping in a tank, to vigorous scrubbing of pineapples with high-pressure water jets. Cleaning may be accomplished with brushes, high-velocity air, steam, water, vacuum, magnetic attraction of metal contaminants, mechanical separation, etc. (Potter and Hotchkiss 1995). The use of clean water is also essential; municipal or local water may require additional treatments such as controlled chemical flocculation of suspended matter, sand filtration, carbon purification, microfiltration, and de-aeration to ensure its cleanliness. Processing equipment and the floors and walls of processing facilities may be cleaned with acid or alkaline detergents, or a combination of both. The use of a sanitizer such as chlorine is recommended after cleaning of food or processing equipment to ensure safety.

SEPARATING

Examples of separating operations include physical sorting or removal of defective, immature, or broken products, shells from nuts, or peels from vegetables; filtration of a liquid and solid material; or pressing of juice from fruit pulp. Recently, new methods of sorting such as magnetic resonance imaging and near-infrared radiation have been developed for horticultural products.

PEELING

Peeling may be accomplished by using steam, water, or lye (sodium hydroxide) solutions, or by using mechanical means such as abrasive peelers. With some horticultural commodities it may be advantageous to use a combination of a hot water scald and steam under pressure. Many processors claim that the quality of fruits peeled with lye is preferable because of the relatively small amount of peel removed and the high flesh retention in the final product. However, the disposal of lye is cause for environmental concern, and a number of companies are moving away from this technique. Mechanical peeling is appropriate for relatively hard commodities, such as apples, pears, and potatoes.

DISINTEGRATING

Disintegrating operations subdivide large sections of food materials into smaller ones. These include chopping, grinding, pulping, homogenizing, dicing, and other size-reduction operations. In some cases the disintegration process may involve heat generation, so it may be desirable to cool the food material and the equipment used.

PUMPING

Pumping of liquids and solids from one location in a processing plant to another is essential, and many different types of pumps are available for this use. For solid materials, the size and fragility of the pieces to be pumped dictate the choice of pump. For example, very gentle pumps have been designed for aseptic particulate processing systems in which particulate integrity is critical to quality. Some of the pump types available include the cam and piston pump, external or internal gear pumps, two- to four-lobe pumps, single- to triple-screw pumps, swinging or sliding vane pumps, sine pumps, and shuttle block pumps (Potter and Hotchkiss 1995).

MIXING

Mixing operations may involve integration of various solids, liquids, liquids with solids, gases with solids, gases with liquids, and so forth. As with pumps, many different types of mixing devices are available, and the choice depends on the physical materials to be mixed.

HEAT EXCHANGING

Heat exchanging includes heating and cooling products, two of the most common unit operations in the processing of horticultural products. In many fruit and vegetable products, thermal treatment is required for destruction of microorganisms and their spores, inactivation of enzymes, flavor or taste enhancement, texture or viscosity adjustments, and numerous other reasons. However, most horticultural commodities are temperature-sensitive, and extended periods at high temperatures may cause undesirable changes in texture, color, flavor, and nutritional quality. To optimize quality,

it is vital to heat and cool fruits and vegetables as quickly as possible. Many different types of heating systems exist, and selection should be based on the specific commodity, end product, and the capital and operating costs required. Products may be heated or cooled using direct or indirect heat. Direct steam injection, frying, dehydrating, and direct flame contact are used with certain fruit and vegetables products. Common indirect heating devices include plate heat exchangers, scraped surface heat exchangers, tubular heat exchangers, steam jacketed kettles, and retorts.

Cooling may be accomplished with some of the same equipment used in heating (for example, most of the heat exchangers), but refrigerant or cold water is the indirect contact medium rather than water or steam. Many fruits and vegetables are refrigerated or frozen as a form of preservation. Freezing may be carried out with air blast freezers, contact freezers, or cryogenic (liquid nitrogen or solid carbon dioxide) freezers.

EVAPORATION AND DRYING

Although evaporation and drying involve the removal of water, evaporation typically involves a 2- to 3-fold concentration whereas drying often takes food to 2 to 3% total moisture. During evaporation, flavor volatiles may also be recovered or removed, according to their desirability. In many cases evaporation is carried out under vacuum so that the water boils off at a lower temperature and thermal damage is avoided. Dehydration is discussed in more detail below.

FORMING

Forming involves pressure extrusion through dies of various shapes, or using molds into which hot products are placed and subsequently cool and harden into the mold pattern. For example, tablet-forming machines are used to produce fruit juice tablets from dehydrated fruit juice crystals.

PACKAGING

Food is packaged in order to protect it from microbial contamination, dirt, insect attack, light, moisture or flavor adsorption or loss, and physical abuse (Potter and Hotchkiss 1995). A wide variety of packaging materials exists, including tin cans, glass and plastic bottles, paper, plastic films, metallic films, and laminates comprised of layers of different materials. Special machines designed to fill and close packages are used to ensure adequate seals.

FERMENTATION

Fermentation is one of the oldest forms of food preservation, and in many less developed countries it still serves as a major preservation method. Fermentation results when microorganisms grow in an anaerobic environment, consuming organic materials for their own metabolism. Although microbial growth is usually undesirable, in this case the select microorganisms that are encouraged to grow produce acids, alcohols, and other compounds that have a pleasing flavor and extend keeping quality. In order to ensure the desired product characteristics, it is common to control the following in a food fermentation: level of acid, level of alcohol, use of starters, temperature, level of O_2, and amount of salt. Some examples of fermented fruit and vegetable products include (Potter and Hotchkiss 1995): dill and sour pickles (cucumbers); green olives; sauerkraut (cabbage); kimchi (mixed vegetables and Chinese cabbage); poi (taro); tempeh (soybeans); soy sauce (soybeans); and wine (grapes and other fruit).

Many types of fermentation, or pickling, involve the use of a salt brine. This is done to create an environment in which the desired type of microorganism will grow. For example, in the manufacture of cucumber pickles, a 5 to 8% salt brine is used to encourage the growth of salt-tolerant lactic acid bacteria and to prevent growth of proteolytic and spoilage microorganisms. Following fermentation, the salt is washed out and vinegar (a preservative that replaces lactic acid) and calcium chloride (a firming agent) are added; the pickles are then typically pasteurized to increase shelf life. Fresh-packed pickles may be produced by adding vinegar directly to the cucumber and then pasteurizing.

Fermentation can actually improve the nutritional quality of foods in three ways: microorganisms synthesize complex vitamins (riboflavin, vitamin B_{12}, and vitamin C) and other growth factors; microorganisms may allow for better digestion of food materials by enzymatically breaking them down into simpler compounds; and microorganisms

may physically (e.g., penetration of mold mycelia) or enzymatically liberate nutrients that are sequestered in indigestible plant parts or cells (Potter and Hotchkiss 1995).

JUICE PROCESSING

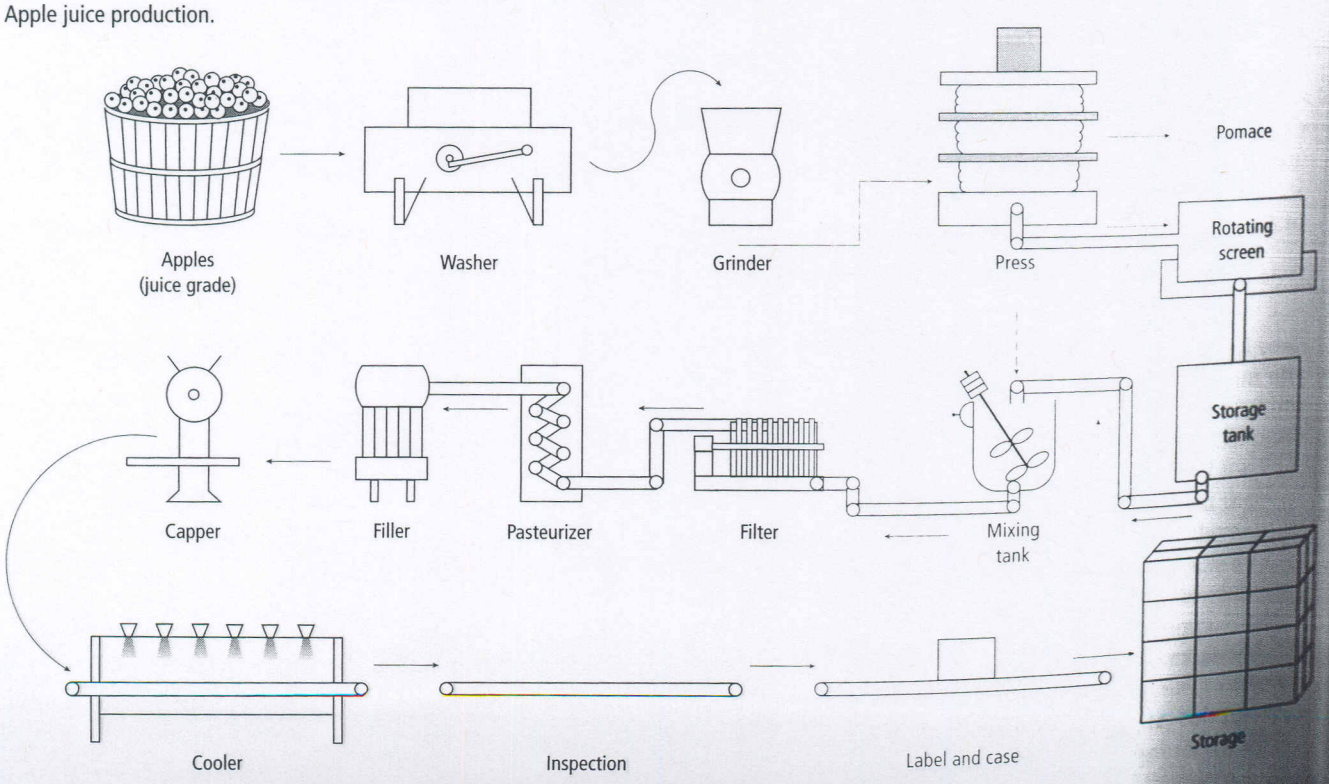
Although juices may be prepared from either fruits or vegetables, the leading juice commodity by far is oranges. Many of the unit operations involved are common to all juice processing, and these may include extraction, clarification, de-aeration, liquefaction, pasteurization, concentration (optional), essence add-back, canning or bottling, and possibly freezing. Apple juice production is illustrated in figure 37.2. Juice extraction typically involves grinding the product, but in the case of oranges and other commodities with bitter peels, the extraction process may require special machinery to extract juice without inclusion of these flavor components. After extraction, the pulp is often clarified using enzymes followed by filters, presses, or high-speed centrifuges. It may be necessary to treat the pulp with digestive enzymes in order to hydrolyze pectic materials and increase the efficiency of clarification (McLellan 1996). In the production of cloudy beverages it is desirable to allow a certain amount of suspended pulp to remain in the juice; many consumers believe that this imparts a more natural quality to the juice.

Removal of entrapped air, or de-aeration, will prevent undesirable oxidation reactions and improve the quality of the juice produced. Special equipment has been designed to efficiently remove air from liquid systems. Pasteurization of juices is often advisable in order to decrease microbial population and inactivate endogenous enzymes. Fruits and vegetables contain the enzyme pectinesterase, which catalyzes pectin demethylation, eventual gelling or settling out of the insoluble pulp. In orange juice production, a temperature of 90°C (194°F) is required for inactivation of this enzyme, while destruction of normal microbial populations requires a process of only 74°C (165°F) (Desrosier and Desrosier, 1977).

Production of high-quality low-acid vegetable juices is a challenge because much of the desirable flavor of the fresh vegetable resides in the pulp, and extraction of these components is difficult. Under normal juice processing conditions, low-acid juices must

Figure 37.2

Apple juice production.



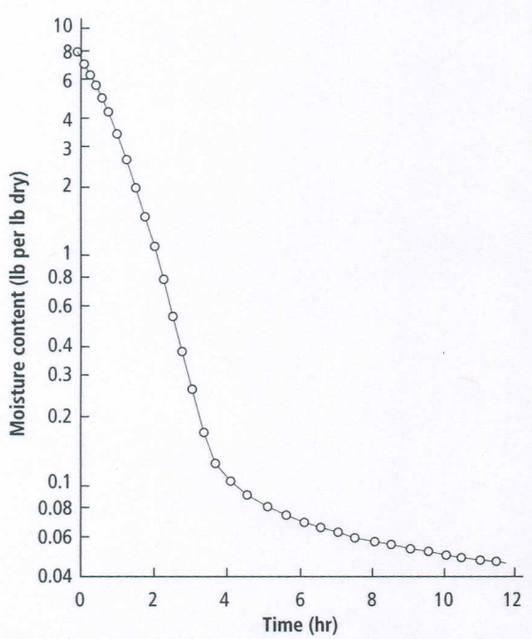
be sterilized at 121°C (250°F) to inactivate enzymes and kill microorganisms and their spores. This process also results in a loss of most of the flavor components typical of the vegetable commodity. It is possible to recover fruit and vegetable essences that are volatilized during pasteurization or concentration and add them to enhance flavor. Concentration is typically carried out in a vacuum evaporator to allow for water removal at lower temperatures and prevent thermal damage to the juice. Membrane filtration methods such as reverse osmosis and ultrafiltration have replaced vacuum evaporators in many juice concentration operations because of the improved quality that these technologies produce. However, membrane filtration systems may be significantly more expensive than vacuum evaporation.

Fruit nectars are another type of beverage that are usually produced from fruit that is low in flavor as a single-strength clarified juice or strongly flavored (McLellan 1996). Fruit nectars consist of a blend of sugar syrup, fruit acid, and high-solids (concentrated) juice or puree.

The nutritional composition of fruit juices and juice blends may be very high, in particular with regard to vitamin C. Apple juice is typically low in vitamin C and is therefore fortified (Potter and Hotchkiss 1995). Consumption of high-quality juices as nutritional beverages is on the rise, and technologies such as aseptic processing that preserve vitamin content are increasingly favored.

Figure 37.3

Drying curve for diced carrots.



DEHYDRATION AND CONCENTRATION

Dehydration refers to the nearly complete removal of water from crops under controlled conditions, causing minimum (or ideally no) changes in food properties (Potter and Hotchkiss 1995). Dehydration of horticultural crops has been practiced for centuries; in environments where drying is slow, microbial growth may be avoided by using either smoke and salt as further preservatives. Although dehydration serves as a form of preservation, it is also useful in reducing weight and bulk, which may lower shipping and container costs. Dried fruit and vegetables products generally contain 1 to 5% moisture, and their shelf life at room temperature may be 1 year or longer. Horticultural commodities may be dried whole (e.g., grape, berries, apricot, plum), in sliced form (e.g., banana, mango, mushroom, papaya, peppers, kiwifruit, tomato), as leather, or as a powder (Ratti and Mujumdar 1996).

The principle of dehydration technology is to get heat into the product and get moisture out. Factors that affect the rate of dehydration include product surface area, temperature, air velocity and humidity, atmospheric pressure and vacuum, evaporation rate and temperature, and overall drying time and temperature. Moisture loss does not occur at a constant rate; the largest percentage of the total moisture in a product is removed in a relatively short time, but it may take as long or longer to remove the remaining moisture. The laws of heat and mass transfer dictate these rates of drying. Figure 37.3 shows a typical drying curve for carrots, illustrating 90% of the moisture is lost in 4 hours, but another 4 hours is required to remove the remaining 10%. In fact, under practical conditions, moisture contents never go to zero. Instead, final moisture levels in most products are below 5%.

Many different methods are available for horticultural crop dehydration, but the most important are sun drying, tunnel or cabinet drying, drum drying, spray drying, and

Figure 37.4

Counterflow tunnel drier construction.

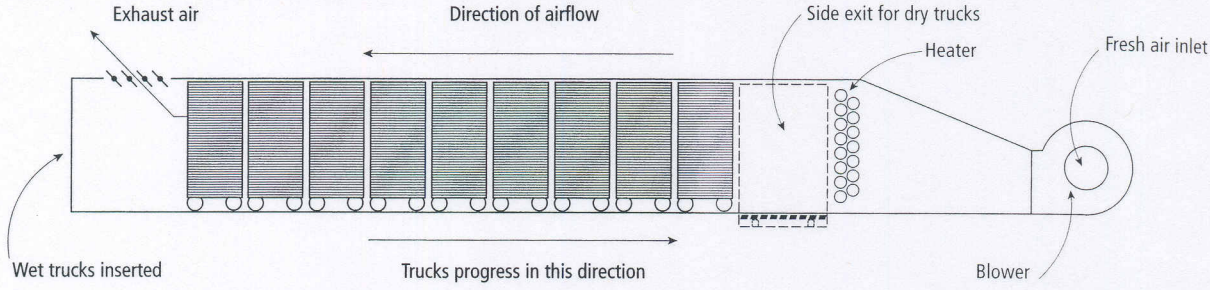


Table 37.2. Common drier types used for liquid and solid foods

Drier	Usual food type
Air convection driers	
Kiln	Pieces
Cabinet, tray, or pan	Pieces, purees, liquids
Tunnel	Pieces
Continuous conveyor belt	Purees, liquids
Belt trough	Pieces
Air lift	Small pieces, granules
Fluidized bed	Small pieces, granules
Spray	Liquids, purees
Drum or roller driers	
Atmospheric	Purees, liquids
Vacuum	Purees, liquids
Vacuum driers	
Vacuum shelf	Pieces, purees, liquids
Vacuum belt	Purees, liquids
Freeze-driers	Pieces, liquids

Source: Potter and Hotchkiss 1995.

freeze drying. Figure 37.4 depicts a counterflow tunnel dryer, which utilizes convection to convey the hottest and driest air to the nearly dry product (Potter and Hotchkiss 1995). Menon and Mujumdar (1987) classified the over 200 types of commercial dryers available based on

- mode of processing (batch, continuous, semibatch)
- operating pressure (vacuum, atmospheric, high pressure)
- mode of heat transfer (conduction, convection, radiation, dielectric, or a combination)
- adiabatic or nonadiabatic (with or without heat exchangers immersed within the dryer)
- physical form of product (granular, whole, continuous liquid etc.)
- physical state of product (stationary, moving, conveyed, vibrated, fluidized, dispersed, atomized, stirred, etc.)

Potter and Hotchkiss (1995) summarized commonly used drier types and the type of food usually dried with each (table 37.2).

Concentration also involves moisture removal, but not to the same extent as used in dehydration. Examples of concentrated fruit and vegetable products include juice and nectar concentrates, jams and jellies, tomato paste, and fruit purees. Concentration is typically not considered a form of preservation, unless the concentrate is high in sugar (≥70% sucrose) or salt (18 to 25% solution) (Potter and Hotchkiss 1995). These concentrated sugar or salt solutions exert high osmotic pressure, which either draws water from microbial cells or prevents normal diffusion of water into these cells, therefore imparting a preservative effect. Concentration may be carried out with a variety of methods, including solar concentration, open kettles, flash evaporators, thin-film evaporators, vacuum evaporators, freeze concentration, or ultrafiltration and reverse osmosis.

Jellies, jams, preserves, and marmalades are all sugar-acid-pectin gels or low-methoxyl-pectin-calcium gels, but the fruit component is incorporated differently in each (Baker et al. 1996). Only strained fruit is used in jellies, while jams are made with either crushed or ground fruit pieces. Preserves consist of whole fruit or large pieces of fruit; marmalades are clear jellies in which fruit slices or shreds are suspended. Processing of these types of fruit concentrates involves blending together the four components (fruit, sugar, acid, and pectin); evaporating to a desired solids or sugar level to reduce moisture available for

microbial growth; and pasteurization of the product to destroy microorganisms.

REFRIGERATION AND FREEZING

Refrigeration and freezing technologies are used to slow the growth of microorganisms and to reduce the rate of metabolism and enzyme-catalyzed deteriorative reactions in horticultural crops. Refrigeration typically refers to the use of storage temperatures above freezing, for example, from 16°C (60°F) to –2°C (28°F) (Potter and Hotchkiss 1995). Commercial and household refrigerators generally operate at 4.5° to 7°C (40° to 44.5°F). Although pure water freezes at 0°C (32°F), most foods do not freeze until about –2°C (28°F), because they contain solids that depress the freezing point. Temperatures of –18°C (0°F) or lower are recommended for maintenance of quality during frozen storage.

Ideally, the refrigeration of fruits and vegetable starts at the time of harvest and continues through each point of the postharvest chain up to the point of consumption. Refrigeration is a relatively gentle form of preservation, and although it maintains horticultural crops in the most "freshlike" state, it cannot compete with more intense preservation methods such as thermal processing or dehydration in prevention of deterioration. Rapid cooling of fruits and vegetables following harvest and throughout storage significantly decreases respiration rates and maintains flavor, color, texture, and nutritional value. For further information on cooling technologies and refrigerated transport and storage, see chapters 11, 12, and 20.

Freezing serves as a method of preservation because water activity can be lowered to levels that prevent microbial activity and reduce the rates of chemical reactions. There are three steps in the freezing process:

- cooling from initial temperature to freezing point (specific heat removal)
- phase change from liquid to solid state (latent heat of fusion)
- lowering temperature from freezing point to desired storage temperature (specific heat removal)

By undergoing a change in state from liquid to solid, water is essentially unavailable to microorganisms for growth or for chemical reactions. As water is solidified during freezing, the concentration of solutes in the remaining liquid becomes greater, and adverse quality reactions may take place unless the freezing rate is fairly rapid. In addition, fast freezing favors the formation of small ice crystals, whereas slow freezing allows large ice crystals to form within and between plant cells. These large crystals may cause physical rupture and separation of cells, which results in undesirable textural changes perceivable on thawing of the product.

There are three basic freezing methods used commercially: freezing in air, freezing by indirect contact with the refrigerant, and freezing by direct immersion in a refrigerating medium. Potter and Hotchkiss (1995) subdivided these three classifications further into specific methods (table 37.3). Still-air "sharp" freezing simply involves placing food in an insulated cold room at –23° to –30°C (–9° to –22°F). Air blast freezers operate at –30° to –45°C (–22° to –49°F), with forced-air velocities of 10 to 15 m/sec (2,000 to 3,000 ft/min) (Potter and Hotchkiss 1995). A special class of air blast freezer called fluidized bed utilizes air velocities that just exceed the free-fall velocity of the food particles. When this high-velocity air is blown up through a wire mesh belt, the particles have a dancing-boiling motion and increased contact with the cold air.

Indirect contact freezers consist of a number of metal plates through which refrigerant is circulated. Flat packages of food are placed between these cold plates, and the plates are pressed together to increase contact. Immersion freezing consists of dipping product into a refrigerant or spraying the refrigerant directly on the product. Two types of refrigerants are available: low freezing point liquids (sugars, sodium chloride and glycerol), which are chilled by indirect contact with another refrigerant; and cryogenic liquids

Table 37.3. Commercial freezing methods

Air freezing	Indirect contact freezing	Immersion freezing
Still-air "sharp" freezer	Single plate	Heat exchange fluid
Blast freezer	Double plate	Compressed gas
Fluidized-bed freezer	Pressure plate	Refrigerant spray
	Slush freezer	

Source: Potter and Hotchkiss 1995.

(compressed nitrogen or carbon dioxide), which cool by evaporating (Potter and Hotchkiss 1995).

THERMAL PROCESSING

Thermal processing is one of the most common forms of food preservation because it efficiently reduces microbial population, destroys natural enzymes, and renders horticultural products more palatable. Varying degrees of heat may be used in fruit and vegetable processing and preservation, and it is important to define thermal processing terms. *Sterilization* refers to the complete destruction of microorganisms and their spores; conditions typically cited are 121°C (250°F) wet heat for 15 minutes or its equivalent. Sterilization of all parts of a container of food requires knowledge of heat penetration rates, whether heating is conductive or convection, and the cold point in the food mass.

In order to maintain the best quality of thermally processed horticultural crops, processors seek to apply the mildest heat treatment that guarantees freedom from pathogens and toxins, and also prevent spoilage. In order to do this, it is vital to know the time-temperature combination required to inactivate the most heat-resistant pathogens and spoilage organisms in a specific food. The most heat-resistant pathogen in foods, especially those processed and stored under low-acid anaerobic conditions, is *Clostridium botulinum*. Determining the process time and lethality to be used requires experience and basic training in the principles of process engineering; particularly in the case of low-acid or acidified foods, process authorities must be consulted to assist with system design.

It is fortunate that many foods do not need to be completely sterile to be safe and have good shelf life. In practice, it is common to produce a food that is *commercially sterile*, meaning that all of the pathogenic and toxin-forming organisms have been destroyed, as well as other organisms that would grow and produce spoilage under normal conditions of handling and storage. Most canned and bottled fruits and vegetables are produced under conditions of commercial sterility and have a shelf life of 2 years or longer (Potter and Hotchkiss 1995). Deterioration that occurs in these products after long-term storage is more commonly caused by texture, flavor, or color deterioration rather than microbial growth.

Pasteurization has been discussed earlier in this chapter in conjunction with the preservation of juices. This is a low-temperature (typically below boiling point of water) process that aims to destroy pathogenic organisms associated with the specific product and to extend shelf life by reducing total microbial population and enzyme activity. Pasteurized horticultural products still contain living microorganisms capable of growth, but this technology is often combined with refrigeration, which assists in extending shelf life. Blanching is a specific type of pasteurization that is often used prior to freezing; its primary purpose is inactivation of natural deteriorative enzymes. Blanching treatments typically result in destruction of some microorganisms, but this should not be the target in setting blanch conditions.

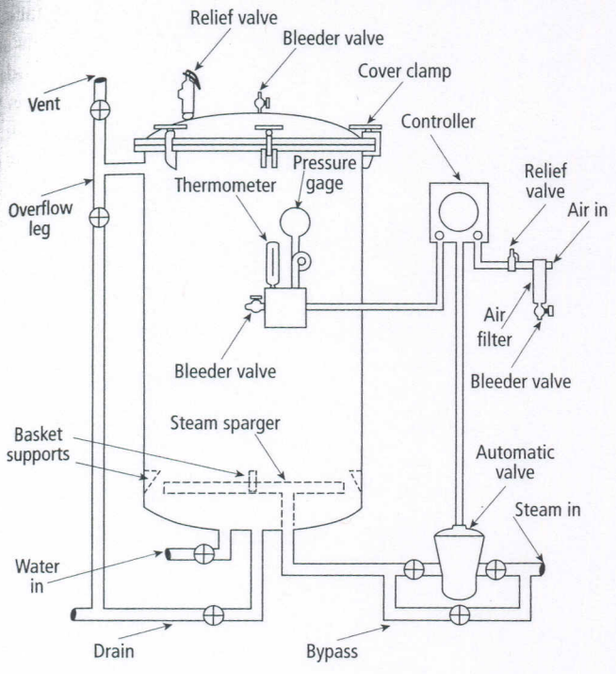
Thermal processing essentially involves either heating foods in their final containers or heating foods prior to packaging and then packaging under sterile conditions. Heating foods in their final containers is common practice and requires little technical sophistication, but product quality may not be as good as the second method due to the slowness of heat penetration. The conventional still retort is in reality very similar to a pressure cooker (fig. 37.5) in which crates containing cans or bottles are placed and exposed to steam under pressure. Equipment available for heating foods in their containers includes still retorts, agitating retorts, hydrostatic cookers, direct flame sterilizers, and in-package pasteurizers. Heating foods prior to packaging may be accomplished by batch pasteurization, high-temperature short-time (HTST) pasteurization, aseptic processing, hot-fill processing, or microwave heating (Potter and Hotchkiss 1995).

IRRADIATION, MICROWAVE, AND OHMIC PROCESSING

Irradiation and microwave processing utilize radiant energy, which changes foods as it is absorbed, while ohmic processing raises the temperature of foods by passing an electrical current through them. These three processes are less common than the ones discussed above, but they have unique applications.

Figure 37.5

Conventional still retort.



Irradiation has been under intense investigation since 1945, and in 1983 it was approved by the U.S. Food and Drug Administration (FDA) as a means for controlling microorganisms on spices. In 1986 the FDA widened the allowed uses to include irradiation of fruits and vegetables at doses up to 1 kGy for the following purposes: as an alternative to chemical fumigation to control insects; to inhibit sprouting in crops such as potatoes; and to delay fruit ripening by a mechanism not well understood (Potter and Hotchkiss 1995; Willemot et al. 1996).

Radiant energy, or ionizing radiation, is radiation of high enough energy to expulse electrons from atoms and to ionize molecules. Ionizing radiation has penetrating power but does not produce radioactivity in treated products, nor does it produce significant heat. Irradiation causes direct effects due to the interaction of high-energy rays and microbial cells or food molecules, and it also causes indirect effects due to the production of free radicals, which also interact with microorganisms and food components (Potter and Hotchkiss 1995). The literature reports varying success in terms of radiation treatments on fruits, and successful application depends on a number of factors, including commodity and cultivar, radiation dose, degree of maturity, physiological status of fruit, temperature and atmosphere during and after treatment, pre- and postharvest practices, cost, and susceptibility of microorganisms to be controlled (Willemot et al. 1996). The food industry is concerned that consumers may believe irradiated products are unsafe. However, studies by numerous federal agencies have unanimously concluded that irradiation does not result in an unsafe product, particularly at the low doses used for pasteurization, sprout inhibition, and insect control.

Microwave energy occurs as alternating electric current at frequencies of either 915 or 2,450 megahertz, which means the electric field reverses 915 or 2,450 million times per second. Water and other molecules in food are dipolar, that is, they have distinct positive and negative ends that oscillate to align themselves with alternating microwave current. These high-speed oscillations cause friction, which heats the food. Microwave heating differs from conventional thermal processing because microwaves are able to penetrate uniformly several centimeters into the food. Heat is generated quickly and evenly throughout the mass, and the steam generated heats adjacent areas by conduction. Microwave heating applications to fruit and vegetable products include concentrating heat-sensitive solutions at low temperatures; cooking large pieces without high temperature gradients; uniform dehydration; rapid enzyme inactivation; combination with freeze drying to accelerate final moisture removal; heating temperature-sensitive products; and controlled thawing of frozen products (Potter and Hotchkiss 1995).

Ohmic processing involves the continuous processing of particulates in a conducting solution by passing them through a series of low-frequency alternating electric currents of 50 to 60 hertz. One major advantage of this process is that there is no significant gradient in the temperature of particulates from inside to outside. Both the particulate and the carrier liquid heat quickly and are then cooled using technology similar to the heating by alternating electrical currents and are packaged aseptically.

ADVANTAGES AND DISADVANTAGES OF VARIOUS PRESERVATION METHODS

Growers of horticultural crops who are considering "adding value" by processing may view the selection of a preservation method as an overwhelming task with no clear choice. However, there are advantages and disadvantages to all of the preservation methods discussed above; summarizing these (table 37.4) should provide some assistance.

Table 37.4. Advantages and disadvantages to selected preservation methods

Preservation method	Advantages	Disadvantages
Fermentation	Relatively inexpensive Simple technology Shelf-stable long time May improve nutrition May improve aroma & flavor of product Acidity prevents microbial growth	Strong flavor and acidity may limit consumption May have light-catalyzed oxidation if in glass Acid may affect thickener selection
Juice processing	Relatively simple technology May be used with poorer-quality fruits and vegetables Improved palatability and digestability of product Canned or bottled products may be quite stable	May require refrigeration May require relatively high capital investment for equipment Settling of pectic materials over time may be unsightly
Dehydration	Relatively low-cost, simple technology Long shelf life if stored properly Reduction in product weight and volume	Potential for nutrient and quality losses May incur insect and microbial damage (esp. sun drying) Economic value of product may be low
Concentration	Very shelf-stable product Reduction in product weight and volume May be used with poorer-quality fruit and vegetables	May require relatively high capital investment for equipment May result in loss of flavor essences unless these are added back
Refrigeration	Relatively simple technology Maintains most "freshlike" appearance Film wraps may prevent dehydration	Equipment required may be relatively costly Short shelf life Merely slows down biological processes Horticultural crops have different optimums
Freezing	Typically carried out within hours of harvest Quality typically very good Nutritional content typically very high	May require relatively high capital investment for equipment Storage life limited Quality degradation may be ongoing unless water is in solid state
Thermal processing	Relatively simple technology Efficient destruction of microorganism and enzymes Long-term storage May increase palatability and digestibility	May require relatively high capital investment for equipment May adversely affect quality and nutritional content
Irradiation	Efficient destruction of microorganisms and enzymes At low doses is preferable to other technologies for certain applications	May require relatively high capital investment for equipment Relatively new and unfamiliar to consumers
Microwave processing	Rapid heating process Quality typically very good Nutritional content may be preferable	May require relatively high capital investment for equipment May be difficult to make continuous process Short shelf life
Ohmic processing	Rapid and uniform heating of both particulates and carrier liquids	May require relatively high capital investment for equipment

PACKAGING

Processed products must be protected from physical damage, chemical attack, and contamination from biological agents such as microorganisms, insects, and rodents. The goal of the packaging industry is to create containers which form a *hermetic seal*, a complete seal against the ingress of gases, vapors, and microorganisms. Jelen (1985) summarized the functional requirements of packaging materials (table 37.5). There are a limited number of packaging materials used for processed fruit and vegetable products, including metal (steel and aluminum), glass,

paper, paperboard, fiberboard, wood, cloth, plastics, laminates, and edible films. The choice of packaging material depends on many things, including the type of food, storage length and conditions, abuse the product may experience, functional properties of the package, and package cost and attractiveness. Thermally processed fruits and vegetables are typically packed in steel cans or glass, but aseptically processed products are often packed in laminates of metal sheet and foil, plastic, and paper. Dehydrated horticultural products must be packaged in containers that prevent exposure to oxygen and light, both of which accelerate quality degradation. Laminates of foil, plastic, and paperboard are often used for dried fruits and vegetables. Frozen products are commonly packaged in plastic pouches, laminated cartons, or composite cans.

QUALITY ASSURANCE IN FOOD PROCESSING

Quality assurance is an organized system of establishing, monitoring, and evaluating safety and quality-related activities associated with processing of a specific product. The quality assurance department of a processing facility may be involved in inspection; laboratory analysis for physical, chemical, and organoleptic quality; sanitation and microbiological testing: and research and development. Quality "assurance" and quality "control" are often used interchangeably, but quality control relates more specifically to the assessment of raw material and finished product quality and safety using standard procedures. In order to determine whether observed variations in product specifications are in an acceptable range, quality control charts are established that document the mean, range, and normal frequency of observed measurements. Statistical quality control charts may be used to monitor specific measurements of size, color, texture, flavor, ingredient composition, nutrients, microbial counts, process temperatures, can seams, and many other variables. Quality assurance is the key to any processing operation, as it allows for control of product safety and quality.

Table 37.5. Functional requirements of packaging materials

Functional property	Specific factors
Gas permeability	O_2, CO_2, N_2, H_2O vapor
Protection against environmental factors	Light, odor, microorganisms, moisture
Mechanical properties	Weight, elasticity, heat-sealability, mechanical sealability, strength (tensile, tear, impact, bursting)
Reactivity with food	Grease, acid, water, color
Marketing-related properties	Attractiveness, printability, cost
Convenience	Disposability, repeated use, resealability, secondary use

Source: Jelen 1985.

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