COMMERCIAL VEGETABLE PROCESSING

SECOND EDITION

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Second Edition

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Preface to the Second Edition

The vegetable processing industry in the United States has made technological progress during the past decade. More computers are being used in handling, processing, and marketing of processed vegetables. In preparing the second edition of *Commercial Vegetable Processing,* we have tried to take this progress into account. We are introducing some new contributors in this edition from the Western Laboratory of the U.S. Department of Agriculture, the National Food Processors Association, and experts in computer application who will make the second edition even more valuable to the readers than was the first edition.

Metric units have been used in this edition except for Chapter 12 entitled "Quality Control." Because the food industry in the United States has not yet changed to the SI system, we have retained the U.S. system for weight and measure in Chapter 12.

Increasing recognition of the importance of vegetable processing to human nutrition has stimulated more consumer interest. The chapter entitled "Composition and Nutritive Value of Raw and Processed Vegetables" has been completely rewritten. The authors of the chapter have made excellent contributions to research on the nutritive value of processed vegetables.

Vegetable processing is a very important industry in the United States. It has greatly expanded the farm produce markets through conversion of perishable produce into a stable form that can be stored and shipped to distant markets. Canning, freezing, and dehydration are the basic methods of preserving vegetables, and they are discussed in detail in chapters 6, 8, and 9. Other chapters cover general principles and methods, microorganisms in relation to vegetable processing, containers, computer applications, pickling, grades and standards, quality control, sanitation and waste management, composition and nutritive value, storage life and quality, and nutrition labeling.

This book has been prepared, in conjunction with *Commercial Fruit Processing,* Second Edition, to serve the food processing industry and students majoring in food science and technology. It should be a valuable reference for plant managers, superintendents, quality assurance managers, researchers, and those interested in technical knowledge on food preservation.

The editors thank the many companies and individuals who furnished illustrative materials for this edition. We acknowledge the valuable assistance of Lesley Haunschild, Clara Robison, Karen Jo Hunter, Diane King, Pam Carpenter, and Carol Cooper who spent many hours typing and proofreading the various chapters. Lastly, we thank Mr. R. Y. Feng for proofreading and checking the figures and tables of all the chapters.

B. S. Luh
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General Principles and Methods

B. S. Luh and G. K. York

Rapid population growth throughout the world raises questions as to how food needs can be met. It is apparent that a large increase in food supplies will be necessary to provide a nutritionally adequate diet for everyone. Fortunately, many countries are developing programs to slow down population growth. They are also expanding their agricultural development programs to attempt to keep food supplies in pace with population. Banishment of hunger and malnutrition from the world depends in large measure on how rapidly agricultural productivity can be increased in the developing countries. Development of processing, storage, transportation, and marketing programs is equally important to make efficient use of farm products.

The ability to extend the period of availability of foods and food combinations in preserved forms that retain their nutritive value and palatability has improved human health, added variety to human diets, and reduced the time for food preparation. Equally important, these gains have been achieved at low cost. Modern food processing technology has greatly expanded the farm produce markets both at home and abroad. The increased need for processed foods has resulted from a rising standard of living, desire for a more diversified diet year-round, expanding urbanization, and an increase in population. The approximate per capita consumption of foods in the United States is presented in Table 1.1.

Table 1.1. Approximate Per Capita Consumption of Foods in the United States

	Retail-weight equivalent (kg)			
Item	1970	1974	1978	1982
Meats, fish, and poultry	104	105	106	105
Dairy products, including butter	152	145	143	137
Eggs	18	16	16	15
Fats and oils, excluding butter	23	23	24	25
Fruit				
Fresh	36	35	36	37
Processed	25	24	25	23
Vegetables				
Fresh	64	64	66	68
Canned	23	24	23	21
Frozen	4	5	5	5
Potatoes and sweet potatoes	37	34	37	36
Dry beans and peas, nuts, soya products	7	7	7	8
Flour and cereal products	64	65	66	68
Sugars and syrups	55	56	60	61
Coffee, tea, cocoa	6	6	5	5
All foods	634	620	632	630

Source: USDA (1983).

FOOD PRESERVATION—AN OVERVIEW

Food processing has many goals. The preservation of perishable foods in a stable form that can be stored and shipped to distant markets all year is a primary objective of much food processing. The basic preserving processes are canning, freezing, dehydration, salting, pickling, and freeze-drying. Processing also can change foods into new or more usable forms and make foods more convenient to prepare.

Food preservation is designed to prevent undesirable changes in foods. Such changes can be caused by the growth of microorganisms or by chemical, physical, and biochemical reactions in the food itself. Examples of undesirable chemical changes include oxidative rancidity of fats and oils, loss of ascorbic acid and other vitamins through oxidation, degradation of pectin, and discoloration. The flavor, color, texture, and appearance of foods can also be affected by the methods and conditions of processing.

Microbial Spoilage

There are two basic principles in preventing microbial spoilage of foods. The first principle is to destroy any microorganisms in the food and prevent recontamination by microorganisms from the outside (Cruess 1958; Lopez 1981), which is the objective of canning. Heat is still the most commonly used agent to destroy microorganisms. The second principle is to alter the environment so as to prevent or retard the growth of undesirable organisms. One can, for instance, prevent growth of microorganisms by removing the available water from foods, and then adding water back to a product just before consumption.

Freezing foods below 0°C not only removes the water necessary for microbial growth but also results in a temperature below that which supports rapid growth. Therefore, food that is frozen has a much longer storage life than unfrozen food with respect to microbial growth. Indeed, it is possible to keep food from undergoing microbial degradation almost indefinitely in the frozen state. The reason foods cannot be kept indefinitely in the frozen state is that enzymatic changes affect the quality of the product.

One can also render the environment unable to support the growth of microorganisms by changing the pH of the medium. A low pH, attained with concentrations of acid that the body can tolerate readily, is widely used to preserve foods. These are termed pickled or fermented foods. Most microorganisms grow most rapidly when the pH is neutral. The rate of growth decreases as the pH decreases, until a point is reached where growth can no longer be initiated.

The microorganisms of public health significance (i.e., those bacteria that cause food infections or intoxication) will not initiate growth at pH 4.5 or less. This is the magic pH of foods—the pH below which foods are considered safe from spoilage by food-poisoning bacteria. A number of organisms, however, can grow at pH levels below 4.5 and spoil foods. Certain acid-tolerant bacteria—such as the lactic acid bacteria, responsible for making cucumber pickles and Spanish olives, and the acetic acid or vinegar bacteria—are capable of initiating growth at pH values between 3.5 and 4.5. They also grow quite readily at neutral pH. Most yeast and molds are capable of growing at initial pH levels of 3.0 and above.

Although some microorganisms have an absolute requirement for oxygen for growth (e.g., the majority of molds and many salt-tolerant yeasts), most bacteria and most yeasts are also capable of growth in the absence of oxygen. Therefore, simple removal of oxygen is not a satisfactory method of food preservation. It can be used, however, in conjunction with other methods to prevent the growth of oxygen-requiring microorganisms. For example, preserves and jams, which can support growth of molds on the surface, are packed under vacuum to prevent growth of these spoilage organisms. Similarly, since fermented or pickled vegetables, such as Spanish olives and cucumbers, will support growth of fungi on the surface in the presence of oxygen, they are packaged in an atmosphere from which oxygen is excluded.

Chemical Changes

The most common reaction occurring in food that causes degradation of quality is oxidation, particularly of vitamins, fats, and flavoring compounds. Because these oxidative reactions occur much more rapidly when catalyzed by enzymes, they can be retarded by heat destruction of the enzymes. Removal of molecular oxygen from a container of food also retards oxidation.

The shelf life of foods in tin containers is shortened when nonenzymatic browning occurs, causing discoloration and flavor changes in the product. Another common form of degradation in foods is the breakdown of pectin. Softening of pickled cucumbers and olives can be attributed primarily to degradation of pectin by pectic enzymes from microorganisms or by a combination of excessive heat in the presence of acid.

Nutritive Changes

In addition to the quality attributes, such as flavor, color, and texture, the nutritive value of food must be maintained as much as possible. The use of sulfur dioxide in dried fruits, for example, also aids in preventing oxidation of ascorbic acid. The ideal in developing a new processing technique or a new food product would involve prevention of the growth of microorganisms and at the same time preservation of the flavor, texture, and nutritive value of the product.

CANNING (HEAT PROCESSING)

Canning, which still is the major method of preserving foods, is founded on the basic premise of destruction of microorganisms by heat and prevention of recontamination. With the exception of certain heat-tolerant bacteria, the lethal temperature begins at about 46–49°C. The exceptions are the endospores of certain types of bacteria, which have considerably higher heat resistance than the vegetative or mother cells of bacteria.

It has been proven experimentally that single-cell microorganisms, bacterial cells, and spores are destroyed at a constant, uniform rate by heat; this rate is characteristic for a given microorganism and for a given food or medium in which it is heated. The constant is referred to as the *specific heat resistance* of a microorganism. The *thermal death time* or *thermal death rate* at which an organism is killed can be determined experimentally in any given food for different types of microorganisms (Natl. Canners Assoc. 1968).

In addition to a constant, uniform rate of heat destruction of microorganisms, there is also a uniform, constant relationship between the thermal resistance time and the lethal temperature. Thus, it is possible to determine the resistance of a given organism in a given food at several temperatures and then, by constructing a graph, to extrapolate these resistances to other temperatures. It is from the extrapolation of such heat resistances that the high-temperature short-time heat process, which is used in aseptic canning, was achieved.

In conventional canning, the food is placed inside containers, the air is removed by vacuum, and the cans are hermetically sealed. The cans are placed in a retort and sterilized with steam. The rate at which heat penetrates into the product in the can must be measured from the slowest-heating part of the can. This is accomplished by placing thermocouples in a can, heating the can, and measuring the rate of temperature increase in various parts of the can. These data are then integrated with the thermal resistance constants and a process time is calculated. The basic heat penetration processes are convection, conduction, and a combination of the two. The constancy of the rate of heat penetration for a given product in a given size container and the ability to measure these constants with accuracy have resulted in the remarkable safety of commercially canned foods (Natl. Canners Assoc. 1968).

Containers

The containers used in commercial canning consist primarily of enamel-coated steel, tin-coated steel, and glass. Plastic containers and other flexible packaging materials suitable for heat processing have been under development in recent years. Their use is steadily increasing in the food industry.

Metal Containers. Electroplating techniques allow can manufacturers to place a uniform, extremely thin, inner coating of tin on steel. For products that are corrosive to tin, there are a variety of lacquers or coatings that can be applied to or in place of the tin layer, giving extra protection. In some instances, tin does more than simply protect the steel. For example, the small amount of tin that leaches from the inner portion of the container helps to stabilize the color of canned asparagus. In addition, tin is believed to play a part in the flavor of tomato juice, which is packed in tin without another coating. Many containers are made of aluminum, a metal that does not rust and is light in weight. The aluminum lids are made to open easily by a pull-out device, and many food containers are now being equipped with these.

Glass Containers. Developments in the technology of glass containers involve not only superior formulation of the glass itself but also improvements in closures. The twist-off lid has resulted in a revolution in the closures of glass containers. Chapter 3 has more detailed information about glass containers for food processing.

Plastic Containers. At present there is widespread use of plastic containers for frozen and dehydrated foods (Sacharow and Griffin 1980). The development of heat-resistant plastics and advances in the technology of sealing and sterilizing them is bringing about more widespread use of rigid or semirigid plastic containers for processed foods.

Processing Equipment

Equipment for conventional canning has been changing from batch to continuous units. In continuous retorts, the cans are fed through a lock similar to that used on a torpedo tube of a submarine, then rotated through the heating chamber, usually under pressure, and cooled continuously through a second section of the continuous retort, in a separate, continuous cold-water cooler, or in a spray cooler. One widely used type of continuous retorts is the hydrostatic cooker (Fig. 1.1) in which the pressure from a column of water is substituted for the thick shell of a normal retort, thus maintaining the high pressure under a head of water and achieving the same temperature as in a normal retort.

The advantage of the continuous retort, in addition to increasing the rate of production of an individual canner, is that the time between filling/sealing the can and its entering the retort is vastly reduced; therefore, the undesirable changes that occur in the product during this time are also reduced.

Commercial methods for sterilization of canned foods with a pH of 4.5 or lower include use of static retorts, which are simply large pressure cookers, where the cans are added to the cooker. Although static retorts are still commonly used, they are being replaced with the agitating retort, which moves the can and the food mechanically, so the heat-penetration characteristics are changed from conduction to convection heating. This allows the total time of the process to be shortened. In using a rotary or agitating retort, the headspace between the product and the top of the container must be sufficient for movement of the product.

Quality of Canned Foods

The quality of canned foods is affected not only by the heat process but also by the methods used to prepare the food. Such preparation involves washing, trimming, sorting, blanching, filling into containers, and maintenance of the headspace in the can upon vacuum closing. The newer developments in canning are involved as much with changes in the preparation of food as with the final processing technique. One example is the swept-surface vacuum evaporator in which purées and juices are concentrated

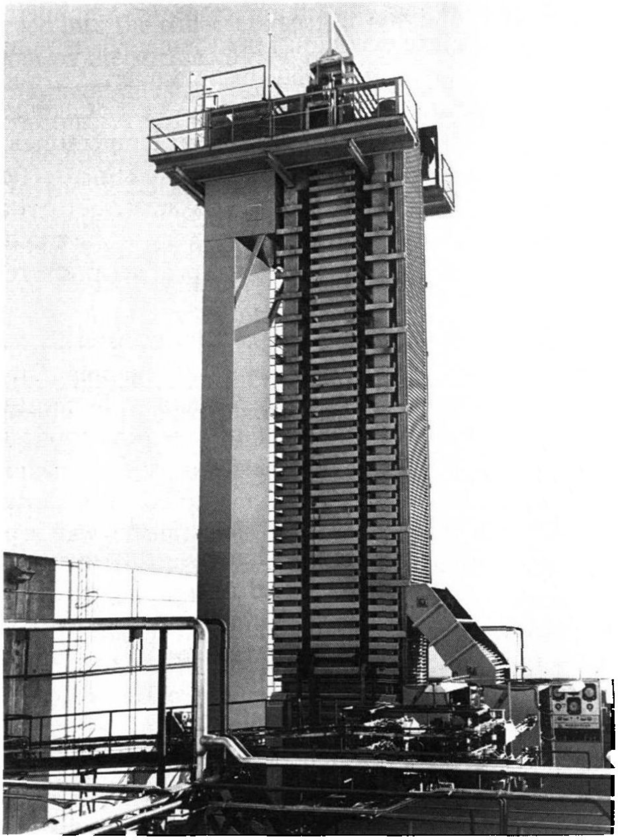

FIG. 1.1. FMC two-pass hydroflex pressure sterilizer (hydrostatic cooker). (Courtesy FMC Corp., San Jose, CA.)

with much less heat than previously was used, resulting in a product with greater storage life, better flavor, and better color.

Aseptic Canning

In the aseptic canning process, the problems of slow heat penetration inherent in an in-container process are avoided by sterilizing and cooling the food separately from the container. The sterilized and cooled product is filled into presterilized containers and sealed in a sterile atmosphere with a sterile cover. Aseptic canning requires (1) an efficient and versatile means of heat-sterilizing and subsequent cooling of the various foods rapidly and uniformly, (2) a means of separately but simultaneously sterilizing the containers and covers, and (3) a way to fill and close the containers in a sterile atmosphere. The approach to accomplishing these goals is to apply a continuous process to both the product and the containers.

During the food sterilization phase, continuous heat exchangers and efficient heat transfer into and out of the product at temperatures well above 121°C are necessary. This dictates operation at pressures sufficiently high to prevent flashing within the heat-exchanger system, but not any higher, and selection of pumps capable of constant delivery of the product through the heat-exchange system against the required product pressure.

Heat Exchangers. The unit operation of heat transfer through a metal wall is indispensable to heat sterilization in aseptic canning. Direct application of a heating or cooling medium to a product is the most efficient of all heat-transfer methods; however, it is limited to those applications where product exposure to and dilution by the heat-transfer medium, namely steam, can be tolerated. The predominant method of transferring heat into and out of a product is through a metal heat-transfer wall separating the heating or cooling medium from the product.

There are several prerequisites to accomplishing efficient heat transfer with minimal deleterious effects on the material being heated. The cardinal requisite pertains to the removal of product film from the heat-transfer surface and the product's resistance to heat penetration or heat release. The major deterrent to the passage of heat through a metal wall is wetting of the heat-transfer wall by product film. All materials immediately adjacent to the transfer wall wet it with a static film that is difficult to remove. This film plays a major role in the efficiency of the heat exchanger. The heat reaching or leaving the material being processed must pass or be driven through this film by conduction. The tenacity of this film and its resistance to removal are direct functions of a product's ingredients and composition, viscosity, solids content, and fat or oil content and of the process pressure. Product film removal is complicated because a major portion of foods is sticky or semifluid in consistency, contributing to reduced thermal conductivity and increased resistance to heat flow.

In cooling operations, in which there is almost always an increase in viscosity and consistency, product film removal from the heat-transfer wall commands special attention. In this case, film resistance becomes acute because the transfer surface is not only wetted by product film but also coated with a high-viscosity or even solidified layer of product.

In heating a product, film removal is the first phase. The second phase of the operation is to impart the heat energy to and through the product. The one function common to good heat transfer is agitation or product turbulence. This is of paramount importance in high-temperature shortterm sterilization where ultimate temperatures range between 140° and 149°C.

Scrape-Surface Heat Exchangers. Mechanically unassisted heat exchangers (e.g., tubular, coil, or plate types) rely on product velocity to create turbulence and product film removal. In mechanically assisted heat exchangers, film removal and agitation are positively induced and created.

In both types of heat exchanger, the most efficient heat-transfer rates are obtained (1) when the heat-transfer surface is kept as clean as practically possible on both the product and jacket sides of the transfer wall, (2) when a relatively small volume of product is exposed to a large area of transfer surface, and (3) when the product volume is maintained in turbulence while flowing past the transfer surface.

If the advantages of high-temperature (140–149°C) short-time (10–30 sec) sterilization are to be realized with products considerably more viscous than milk or cream and with products containing discrete particles, a heat-exchanger system other than coils, tubes, or plates is needed. The major drawbacks of such ordinary mechanically unassisted heat exchangers are the excessively high pressures created, and inherent "burn-on," which eventually lead to surface fouling and subsequent progressive lowering of production capacity.

In a mechanically assisted scrape-surface heat exchanger (Fig. 1.2), the spinning shaft with scraper blades constantly and rapidly cleans the heat-transfer surface 500–1000 times per min, thus preventing scorching and localized over-cooking. The large amount of heat-transfer surface relative to a small volume of product fulfills the requirement for very high heat-trans-

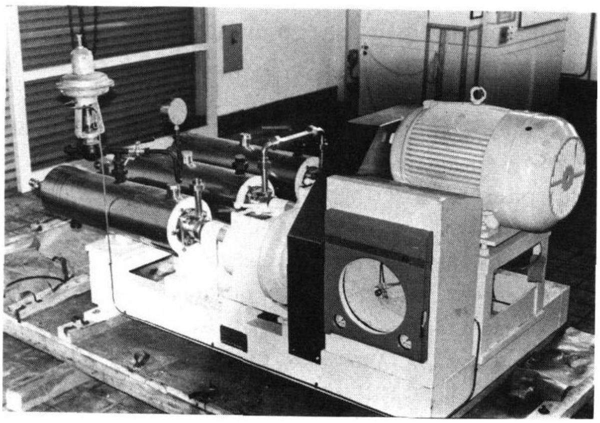

FIG. 1.2. Scrape-surface heat exchanger. (Courtesy Clarke-Built Ltd., The A.P.W. Company Ltd.)

fer rates. Turbulence is created by the revolving shaft and blades under controlled conditions. The combination of uniform agitation of a relatively small volume of product and its efficient removal from the heating surface ensures precise and uniform penetration of heat through every particle of product. This synchronization of product flow, agitation, and maintenance of a clean heating and cooling wall assures an end product with better color, flavor, and aroma than is possible by conventional methods. The product is sterilized with no portion over-processed. Specially designed shafts and blades, as well as control of the annular space between the heat-transfer wall and the shaft, allow processing of products containing discrete particles.

The advantage of the aseptic canning process over the conventional process is based on the kinetic difference between thermal destruction of nutrients and thermal inactivation of microorganisms. Microorganisms are destroyed much faster than vitamins under the high-temperature short-time (HTST) processes. Commercial sterilization of puréed foods can be accomplished by passing them through a Votator type of heat exchanger at 138–149°C in less than 30 sec. Puddings, sauces, soups, and products containing rice and cheese are improved by the HTST process used in aseptic canning (Brody 1972, 1973A,B; Carlson 1969; Leonard *et al.* 1964).

Dole Aseptic Canning System. The Dole aseptic canning system carries out simultaneous canning operations in a closed, interconnected system as a continuous process. The several operations are synchronized mechanically so that the product, containers, covers, and finished canned product move through the system without interruption. Temperature controllers and an alarm system are included in the design of the equipment. The liquid food product is pumped continuously under pressure through the heating section of the sterilizer, in which it is quickly brought up to sterilization temperatures (135–149°C), then through a holding section for the determined length of time to ensure complete sterilization, and finally through a cooling section to the Dole aseptic canning system. The process temperature is controlled by a controller-recorder type instrument, and the process time by the rate of flow of the product through the system. This system constitutes, in effect, a continuous-flow pressure cooker.

Four types of heat-exchange equipment may be used in this system: steam-injection, swept-surface (or scrape-surface), tubular, and plate. The type of exchanger utilized is in part determined by the nature of the product to be sterilized. The standard tubular exchanger requires cleaning at regular intervals to remove product, which tends to build up on the tubing walls. The plate-type exchanger has in the past had pressure limitations, but new designs have corrected this limitation. The swept-surface type has a rotor equipped with scraper blades to prevent the accumulation of product on