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| Reference | _____ |

COMMERCIAL VEGETABLE PROCESSING

Second Edition

EDITED BY

Bor Shiun Luh

*Department of Food Science and Technology
University of California
Davis, California*

and

Jasper Guy Woodroof

*Department of Food Science
University of Georgia
Experiment, Georgia*

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Preface to the Second Edition

CHAPTER 1 General
B. S. Luh and G. K. Woodroof
Food Preservation—
Canning (Heat Processing)
Freezing
Concentration
Refrigeration
Dehydration
Freeze-Drying
Pickling and Fermentation
Radiation Preservation
Bibliography

CHAPTER 2 Microbiology
of Vegetables

E. J. Hsu
Microbial Groups Associated with
Control of Microorganisms in
Microbiological Characterization
Storage
Microbiological Examination
Current Status of Microbiology
Bibliography

CHAPTER 3 Tinplate Cans
*H. C. Chen, C. Y. V. Chen, and
G. K. Woodroof*

Contents

| | |
|---|------|
| Contributors | xi |
| Preface to the Second Edition | xiii |
| CHAPTER 1 General Principles and Methods | 1 |
| <i>B. S. Luh and G. K. York</i> | |
| Food Preservation—An Overview | 2 |
| Canning (Heat Processing) | 4 |
| Freezing | 12 |
| Concentration | 17 |
| Refrigeration | 18 |
| Dehydration | 23 |
| Freeze-Drying | 26 |
| Pickling and Fermenting | 27 |
| Radiation Preservation | 29 |
| Bibliography | 30 |
| CHAPTER 2 Microorganisms in Relation to Vegetable Processing | 33 |
| <i>E. J. Hsu</i> | |
| Microbial Groups Associated with Vegetables | 34 |
| Control of Microorganisms in Processed Vegetables | 42 |
| Microbiological Changes in Canned Vegetables During Storage | 63 |
| Microbiological Examination of Processed Vegetables | 68 |
| Current Status of Methodology | 79 |
| Bibliography | 81 |
| CHAPTER 3 Tin, Glass, and Plastic Containers | 87 |
| <i>H. C. Chen, C. Y. Wang, and B. S. Luh</i> | |
| Tinplate Cans | 88 |

J. G. WOODROOF

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5

Preparing Vegetables for Processing

J. G. Woodroof

Processing begins in the field for many vegetables. This is true with mobile harvesters for greens, viner/shellers for peas and beans, juice extractors for tomatoes, and graders/washers for many vegetables. The advantages of such operations are that harvesting/processing can be stopped or started at any point to accommodate variations in the field; there is no lag in time in which freshly harvested, sometimes badly bruised, product can deteriorate while waiting for the next step in processing; and most of the refuse, including vines, shells, leaves and other organic waste, is scattered over the fields and can be incorporated into the soil. There are several steps common to the preparation of most vegetables for processing.

BASIC STEPS IN PREPROCESSING

The operations involved in preprocessing vegetables for canning, freezing, dehydration, or pickling can be summarized as follows:

1. Harvest in the immature, tender stage, before any portion becomes fibrous and tough. Corn should be full grown, but tender; peas and beans should be "green"; stalks of asparagus, stems of greens, and shells of snap

beans should be without fiber. There is a tendency for most vegetables to be harvested after the peak of quality.

2. Grade to remove trash, overmature, diseased, insect-infested vegetables, and other materials that would impart an off-flavor to the product. This may be done with a roller-grader/sizer, a blower, or rod/shaker, followed by hand inspection. Bruising or cutting, which may cause loss of juices, should be avoided.

3. Weigh to ascertain pay rate, yield, and production rate.

4. Rinse in water to remove surface dirt, insects and small trash not removed by the blower. A detergent may be used on vegetables taken from the soil (e.g., potatoes, sweet potatoes, and turnips) and leafy vegetables (e.g., spinach and turnip greens), provided it is thoroughly rinsed off.

5. Prepare as required for individual vegetables. This includes peeling (beets, carrots, parsnips, potatoes, sweet potatoes); shelling (beans, lima beans, peas, blackeye peas); shucking (corn, cauliflower, Brussels sprouts); trimming (snap beans, okra, broccoli, and others as needed); and cutting and dicing (carrots, beets, sweet potatoes, okra, and others as desired).

6. Blanch or scald at 190°F (88°C) to stop all life processes and destroy yeast and mold; to inactivate enzymes that would cause discoloration and changes in flavor and aroma; to render the product limp and easier to pack in containers; to fix the green color; and to remove certain harsh flavors common in vegetables such as turnip greens, collards, spinach, okra, and snap beans.

Vegetables that are harvested and hauled to the processing plant should be kept cool. Most short, overland hauls are made at night to avoid the heat of the sun. Sometimes the product is hydrocooled and hauled in refrigerated trailers. Examples of this are carrots hauled from southern Texas to western North Carolina to be made into baby food, and okra hauled from Mexico to Georgia for freezing.

Freshly harvested, bruised, and partially processed vegetables have a very high respiration rate and begin to "heat," lose green color, and develop off-flavors within 3 hr when piled more than 6 in. (15 cm) deep. Trickling cold water through the pile is an excellent means of keeping vegetables cool for as long as 6 hr in transit. This must be thorough, however, or the top and sides of the pile may be cool, while the center heats up. Heating may raise the temperature to 29°-32°C and cause the growth of slime and mold. Wetting the surfaces without keeping the product cool is worse than not wetting it at all.

Where hydrocooling or trickling water are not practical in transit, cooling may be accomplished by air circulation. In this case, the vegetables must be in shallow lugs, with holes to permit passage of air through the product. The lugs should be stacked so as to allow the air to pass around them.

Finally, a means of forcing the air into the containers is necessary. There is no satisfactory means of air-cooling vegetables hauled in bulk.

PREPROCESSING OF TOMATOES

In California, 6.5 to 7.0 million metric tons of tomatoes are processed annually in canneries. It is difficult to dispose of the seasonal waste materials in municipal systems, and canneries install secondary or tertiary waste-treatment processes that add substantially to processing costs. Decentralization of processing is highly desirable and would help reduce the costs of waste disposal.

Mechanical harvesting has aggravated the waste disposal problem and decreased yields below the potential. Even though plant breeders have developed tomatoes with tough skins and firm flesh, rough handling during mechanical harvesting still causes significant damage. Once damaged, tomatoes deteriorate rapidly because of microbiological and enzymatic actions. This causes a 10-20% loss in tomato solids during the usual 24-hr interval between harvest and factory processing, including an allowance for hauling mold losses. The damaged fruit ends up in urban waste and is a direct loss.

Field Processing

If tomatoes were processed into a stable macerate or juice in the field, and the macerate or juice transported in bulk to the cannery, the waste discharged to municipal systems would be reduced and the total yield would be increased. In addition, processing in field stations provides an area for disposing of waste water by using it for irrigation either on unharvested tomatoes or on other crops.

A mobile field-processing plant for tomatoes was successfully operated adjacent to fields in northern California (Miers *et al.* 1971). Mechanically harvested tomatoes were processed at 500 lb/hr (181 kg/hr) through the unit within 6 hr after harvest. There was a 9.5% saving of produce compared with tomatoes that were held for 24 hr before processing and an increase of 4.3% in solids recovery after acid treatment of the hot macerate. Thus, a total increase in yield of 13.8% was achieved with field processing. Either single-strength or concentrated material was suitable for bulk transport to a cannery for storage, additional concentration, or immediate formulation into sauces, catsup, or other tomato products.

Processing in the field should be integrated from picking to finishing the final products, and standard equipment can be used throughout. The field-processing operations should be permanent installations, central sorting and washing operations described by Schultz *et al.* (1971).

Washing in Lye

Fruit flies are a plague to most tomato canners and juice manufacturers. They can be so bad that plant shutdown may be necessary while the fruit is still good. *Drosophila* is one of the worst pests. This fly deposits eggs deep into the flesh and cracks of the fruit, where they cannot be washed off by normal means.

A method of destroying the eggs of this insect worked out in Maryland (Murphy 1965) involves washing the tomatoes via fluming to remove surface dirt as soon as they enter the plant, treating the fruit with 0.5-1.0% lye at 120-130°F (49-54°C), and double-rinsing in water to remove 99% of the insect eggs, lye, and tomato peel.

By removing a high percentage of the fly eggs with lye, the packer suffers minor penalties, even though there is no significant difference in pH and other qualities of the tomato product. First, the water demand in the washing system is increased, with more nozzles with pressure of 50 psi added. Second, a decrease in yield of up to one case per ton may result; and third, there is an increase in cost of operation. For these reasons, lye peeling is recommended only in cases of severe fly infestation. When this system is used, proper lye concentration, product temperature, and thorough rinsing are essential.

Peeling

Lye Peeling. Tomatoes can be lye-peeled by immersion in a high-volume machine using a principle successfully applied to fruits. In this procedure, a roller conveyor spreads tomatoes uniformly into machines, where they are picked up by traveling buckets on an endless conveyor that takes them through the immersion tank filled with 14-17% lye solution. A short-time exposure at relatively high temperatures, combined with vigorous agitation, results in high skin-removal efficiency (87-90% removal). Exposure time, temperature, and lye strength can be varied to give optimum results with the particular characteristics of the lot being peeled.

After the buckets leave the immersion tank, they go into an atmospheric steam chamber where the skin loosens, while the lye solution drains back into the tank. A conveyor loop lengthens the holding time. The bucket then dumps the tomatoes into divider channels, and they fall through a rubber boot chafing section, which further loosens the skin. Loose skins are then removed as the tomatoes go through two washing baths and past a rotating brush, with fresh water running countercurrent to product flow. Peeled tomatoes are flumed to inspection belts and can fillers. This process reduces floor space to one-third compared with hot-water peeling (Anon. 1970A).

Freeze Peeling. A process of peeling tomatoes using low-temperature short-time freezing was reported by Brown *et al.* (1970) and Anon. (1970B). Liquid nitrogen (-196°C) is used as the refrigerant for freezing the skin and a thin layer of cells just beneath the skin. The fruit is immediately thawed, after which the skin is quickly and easily removed from the fruit. The loss in peel and trim was about 50% less and significantly less lycopene was lost during nitrogen peeling than during hot-lye peeling. There was a decrease in the amount of broken fruit in canned tomatoes peeled by liquid nitrogen; in addition, titratable acidity and $^{\circ}\text{Brix}$ were higher and pH was lower in these samples. Color of the homogenized canned produce was not different; however, the nitrogen-peeled tomatoes had a better visual color.

Peeling in Calcium Chloride Solution. Another method of peeling tomatoes is by submerging them in a hot solution of calcium chloride (CaCl_2). In this method, the underskin or mesocarp of the tomato is not removed; therefore, the finished product has a better appearance and color than product obtained by lye peeling. Higher drained weights and original shape were obtained, and the firm whole tomatoes could be sliced in a manner similar to whole fresh tomatoes.

Stephens *et al.* (1967) used a rotary-drum peeling machine to submerge tomatoes in a hot CaCl_2 solution and found that the cultivar tested continued to absorb calcium if allowed to remain in the peeling solution after the skin ruptured. They also found that when tomatoes were peeled in calcium chloride and then covered with juice made from the peel trimmings and pieces of tomatoes (tailover juice) that had been peeled in calcium chloride, the resultant calcium chloride exceeded the permissible amount of 0.026% of the weight of the finished canned tomatoes.

In these studies, the drained weight of the tomatoes increased as the submergence time in the CaCl_2 solution increased. The drained weight of CaCl_2 -peeled fruit for all peeling treatments was statistically greater than that of water-peeled fruit. The amount of calcium taken up by the tomatoes increased as the dipping temperatures were raised. The total amount of calcium taken up by a No. 303 can of tomatoes increased as the submergence time increased. Tomatoes treated with CaCl_2 formed calcium pectate with the pectic substances in the tomatoes. The $^{\circ}\text{Brix}$ was a little higher in most of the samples treated with CaCl_2 than in the water-peeled sample.

There are some disadvantages that canning plant operators must consider if they use CaCl_2 as a peeling medium for tomatoes. The use of the process will require constant supervision by a trained operator if a high percentage of peeled tomatoes is obtained from different varieties harvested on different dates. Furthermore, Stephens *et al.* (1973) found that it was impossible to control the amount of calcium taken up by the tomatoes from the hot CaCl_2 peeling solution by adjusting the submergence time.

BLANCHING

The purpose of blanching is to prepare vegetables for the next step in processing. There are many ways of doing this, depending upon the kind of vegetable and the end product desired. Many methods of blanching have been used in an attempt to reduce the leaching of nutrients and to get uniform heating throughout the product.

To blanch produce that is to be canned, the vegetables may be heated with steam or hot water, and the water discarded, carrying with it certain undesirable bitter or harsh flavors. This is done with canning greens, such as turnip greens, spinach, and collards, and with whole pods, such as okra and snap beans. While some chlorophyll and vitamin C are lost in the blanching water, the flavor is milder and improved in acceptability than the unblanched frozen product. Other vegetables are preshrunk and effectively blanched in the peeling process, and then are sliced or diced and put directly into the cans. Among these are whole potatoes; cut sweet potatoes, pumpkins, and squash; diced carrots and beets; and flame-peeled pimientos. In canning, the blanched product is packed without cooling and much of the heat of blanching is used in the sterilizing process.

No step in vegetable freezing is more controversial than that of blanching. The controversy centers on the following questions:

1. Is blanching necessary? The answer is NO if the vegetables are to be consumed within 60 days or less. Fresh corn frozen in the shucks is an example. After 6 weeks in the freezer, frozen unblanched corn has more sugar and natural flavor than frozen blanched corn. Other unblanched vegetables that are properly washed, graded, and packaged before freezing have superior color, flavor, and texture, when eaten within 2 months, compared with the corresponding frozen blanched product. Beyond that time, the unblanched vegetables gradually become tough, more fibrous, less sweet, and without attractive aroma and flavor. These qualities continue to deteriorate, and most frozen unblanched vegetables lose their "freshness" after about 6 months. After a year or more, the aroma and flavor become offensive to the cook with a pronounced "haylike" quality.

2. Do all vegetables need to be blanched? Again, the answer is NO. For example, certain flavors and aromas in onions, peppers, herbs, and spices are very sensitive to hot water and steam, and blanching does more harm than freezing does good. However, most commercially frozen vegetables require blanching if they are to be stored for longer periods of time.

3. Does blanching damage vegetables? YES. Blanching with hot water, steam, or combinations weakens cell walls, causing leaching of some minerals and destruction of some vitamins.

4. What are the advantages of blanching? Blanching is beneficial in

many respects. It leaches out certain harsh flavors such as bitterness in okra, beans, turnip greens, and collards. It is a substitute for parboiling such vegetables as polk salads. It inactivates enzymes that could cause loss of desired aroma, flavor, color, and texture, and renders vegetables limp so that they can be packaged with ease. Blanching cleanses and partially sterilizes the product and accentuates the color of green vegetables.

5. What method of blanching produces the most benefit and least damage? Immersion in 200°F (93.3°C) water followed by immersion in cold water, the most common blanching method, has the objection that it double-leaches the product. Leaching can be reduced by serial blanching, that is, using the same blanching water many times, and by using the cooling water continuously.

Since leaching is reduced after there is a buildup of leached-out minerals in the blanching water, addition of certain minerals to the blanching water helps to stabilize the leaching process. In this technique, the quality and kind of each added mineral is adjusted for each vegetable blanched. For example, calcium might be harmful by "firming" certain vegetables, while magnesium or phosphorus might be beneficial.

Since 1940, steam has replaced hot water for blanching most vegetables except greens, which tend to "matt-together," resulting in uneven blanching. Steam is fast and thereby causes less leaching of minerals. However, the benefits gained by steam may be lost by the excessive amount of water used in cooling. Therefore, nutritionally there is little advantage of steam over water blanching.

The trend since about 1950 is to blanch in less time, with less water, and with less energy. One way is to subject steam-blanched vegetables to a current of dry air, so that cooling occurs by evaporation of the surface water. Evaporative cooling is excellent for most vegetables. When the process is carried beyond the evaporation of surface water, dehydration of the product begins. This is the basis for *dehydrofreezing* in which certain vegetables are blanched and partially dehydrated before packaging and freezing.

Another trend in blanching since about 1970 has been the use of microwaves, which eliminates leaching and reduces blanching time to a few seconds. Studies are in progress on the technology of applying microwaves to prepared vegetables having particles of different sizes, moisture content, and internal structure; exhibiting varying sensitivities to oxygen, and undergoing different changes in color, aroma, flavor, and texture. The problem of cooling microwave-blanched vegetables has not been solved.

6. How long should vegetables be blanched? Adequate blanching requires that each particle of prepared vegetable be heated to an internal temperature of 100°C (212°F). For most vegetables that requires 2-3 min, but there are wide variations. Spinach, kale, turnip greens, and other greens will blanch in 1.5 min; small shelled peas, beans, and cut corn in 2 min;

large (Fordhook) lima beans, short-cut snap beans, okra, carrots, and other vegetables of similar thickness in 3 min; whole pod okra, asparagus, Brussels sprouts, broccoli, cut turnips, rutabagas, parsley, beets, and others of similar thickness in 4 min; and corn-on-the-cob, chunks of sweet potatoes, rutabagas, whole cauliflower, and other large pieces in 8-10 min.

It is important that vegetables not be overblanched, resulting in excessive leaching of minerals, colors, vitamins, and flavor. After storage for 4 months underblanched vegetables will begin to develop a "haylike" flavor, while overblanched vegetables will lack flavor.

Cut surfaces are the source of much leaching during blanching and cooling. Unpeeled or uncut okra, turnips, beets, snap beans, parsnips, squash, and other vegetables will retain more flavor than similar peeled or cut vegetables.

Testing for the Adequacy of Blanching

There are two enzymes—catalase and peroxidase—in rapidly growing vegetable tissue that are partially or completely inactivated by blanching. Enzyme activity may be tested by a sophisticated, time-consuming method described by Decker (1977) or by simply adding a drop of 0.5-3.0% hydrogen peroxide to the freshly cut surface. In the simple test, the appearance of a pinkish-orange color indicates the presence of peroxidase, while a profusion of bubbles indicates the presence of oxidase. The extent of bubbling and coloration parallels the presence of the enzymes, but is not quantitative. Complete enzyme inactivation is not desirable, since that parallels the flavor-leaching process.

IRRADIATION OF VEGETABLES

Since about 1945 considerable public monies have been invested in research on the use of irradiation to prevent postharvest losses in vegetables for the fresh market and processing. Early optimistic reports were based on results with stationary equipment. Extensive studies in California (Maxie *et al.* 1971) and elsewhere, employing actual and simulated transit equipment, have yielded largely negative results. Results show that conventional refrigeration is still the best means of reducing postharvest losses. Furthermore, refrigeration is cheaper, noninjurious, and more effective than irradiation.

Studies have shown that the use of 5-15 krad to inhibit growth of cut asparagus was not economical due to the short season and small crop; use of 100-150 krad to inhibit rot in harvested tomatoes resulted in abnormal ripening and tissue softening; use of 100-200 krad to inhibit stem growth and cap opening of mushrooms was more expensive and less effective than alternative methods; and use of 8-15 krad to inhibit sprouting of potatoes

was more expensive and less effective than alternative methods of accomplishing the same results.

Many commodities have not been studied, but the diversity of species that have been tested and the overwhelmingly negative results obtained indicate that irradiation holds little promise for preserving harvested vegetables.

REMOVING POTATOES FROM STORAGE TO PROCESSING

In 1971, potatoes used for processing exceeded those sold for table use for the first time (Anon. 1972). In that year, the amount of the crop processed was 52% compared with 48% for table stock. The trend toward greater use of potatoes for processing has continued.

Most of the potatoes grown in the fall crop are stored from a few weeks to several months. Those destined to reach the consumer as chips, french fries, or flakes (referred to as *processing potatoes*) are kept at temperatures ranging from 40-80°F (4-27°C), depending upon the variety and condition of the potatoes. The required storage temperatures and ventilation are provided through a system of ducts or floor trenches beneath the piles. The potatoes are stored directly from the fields, in huge piles in specially constructed warehouses that permit most economical loading and unloading.

Orr (1971) evaluated methods of removing potatoes from bulk storage to processing plants, including fluming, hand forking to conveyors, powered bulk-scooping, in-trench unloading, and pallet "tote" box handling. He concluded that fluming from deep-bin storage was less expensive than hand forking or conveyors. The effect of type of storage on fluming costs was small but the lowest-cost system was the cross-alley storage; the door-per-bin was the next lowest cost system, followed by the deep-bin. Bulk-scooping was less expensive than fluming for removing potatoes from cross-alley storage of 60,000- to 120,000-cwt ($3.0-6.1 \times 10^6$ kg) capacity, but in the 42,000-cwt (2.1×10^6 kg) size, fluming was more economical. In addition, fluming "cushions" the fall and rubbing of potatoes, and the presoaking offered by fluming is advantageous in loosening heavy soil that tends to stick to the potatoes.

The fluming system described by Orr (1971) consists of lateral flumes passing beneath the potato piles in the bins, a main flume into which the laterals discharge, a conveyor or elevator that evenly feeds the potatoes to the packing line, a centrifugal pump for recirculating the water, and proper hose sections through which the water flows from the pump to the bins for sluicing. Through a simple arrangement of valves the pump is also used to periodically flush out the dirt and debris deposited in the sump during fluming.

PEELING

Dry-Caustic Peeling

A new dry-caustic peeling system substantially reduces peeling waste of potatoes and other root vegetables. Known as the USDA-Magnuson infrared antipollution peeling process, this system uses infrared energy at 1650°F (899°C) to condition the surface of the vegetable treated with strong sodium hydroxide solution. The peel can then be removed mechanically with soft rubber scrubbing rolls rather than by water, as in conventional caustic peeling. A fine spray rinse using low volumes of water removes the residual peel fragments and excess sodium hydroxide. The effluent from the peeled potatoes may be combined with the solid material generated to produce a thick, pulp sludge.

The success of the dry-caustic peeling process is attested by its wide acceptance and use in the processing of potatoes. It is rapidly being applied to other vegetables and fruits. For potatoes the soaking period is followed by exposure to infrared radiation to accelerate the lye action.

The advantages of dry-caustic peeling compared with peeling operations previously utilized include reduced processing costs, reduced volume of plant effluents and quantity of organic load, and increased product yield and by-product recovery. The process provides the food-processing industry with a way to avoid waste or modify it to produce a waste form that is pumpable and that may be used for cattle feed with further treatment. This factor represents an important saving, not only to processors but to the communities, as it eliminates the expense of sewage treatment of waste effluents (Woodroof 1986).

Commercial applications of dry-caustic peeling began in 1971. Testing and trial runs have been made on tomatoes, carrots, beets, sweet potatoes, peaches, and apricots.

Flame Peeling

The thick, tough skin of certain vegetables, particularly whole, ripe pimientos, can be easily removed after charring at a temperature above 500°F (260°C). The duration of heating is less than 1 min, not long enough to cook the product.

The type of flame peeler used in Georgia, California, and Argentina consists of a slightly inclined cast-iron tube, about 10 in (25.4 cm) in diameter and up to 18 ft (549 cm) long, that slowly rotates as pods of peppers pass through by gravity into a flame of natural gas at the lower end. Baffles control the speed at which the peppers pass through the tube. A commercial plant may operate up to 12 peelers, each with a daily capacity of 10 tons.

The flow of peppers into the peelers is controlled by baffles on a conveyor belt. After passing through the peelers, the peppers are collected on a conveyor belt, which carries them to brushes and washers.

A second type of flame peeler consists of a series of upright iron spikes on a conveyor belt, on which cored pods of pepper are placed; these then pass through horizontally mounted natural gas flames. Due to the large amount of hand labor required to place each pod on a spike and later to remove them, this method of peeling is used only when the cores are removed for saving the seed.

Flame peeling is used to a limited extent with other thick-skinned vegetables such as squash and potatoes.

Peeling Sweet Potatoes

Many methods have been used for peeling sweet potatoes, including boiling, steaming, steam pressure, explosion, lye, or a combination of these. All these involve application of moist heat to the whole potato long enough to soften, loosen, or disintegrate the peel.

Boiling. Boiling sweet potatoes for 20–25 min and dumping them into cold water as a means of softening the peel prior to removal by hand has been found unsatisfactory. The peel becomes waterlogged, soft, and very messy to remove either by hand or machine; also there is no clear demarcation between the peel and tissue beneath, resulting in excessive peeling loss and an unattractive product. The disposal of the large amount (40–60%) of disintegrated peeling produced in this method requires continuous washing of equipment and hands; and the peeled potatoes are semicooked and soft, rendering slicing or packing whole very difficult. It is also necessary to grade potatoes rigidly for size and to treat each lot on the basis of the diameter of the potatoes.

Live Steam. Live steam loosens the peel of sweet potatoes in 30–35 min with less waterlogging than occurs with boiling. The objections just described in the section on Boiling apply to this method of peeling, only to a slightly lesser degree.

Steam Pressure. Steam pressure at 15–20 psi for 5–6 min, with sudden releasing, is a very satisfactory method for loosening and rupturing the peel of sweet potatoes. Small air pockets form immediately beneath the peel, making it easy to remove virtually the entire peel in one piece without injury to the tissue beneath. The length of the treatment is critical; the peel must be removed without cooking the underlying tissue. Admitting cold water into the retort serves to reduce the pressure suddenly and to cool the potatoes. Since only the peel is softened, the peeling loss is moderate (35–

40%), and the peeled potatoes can be satisfactorily sliced or packaged whole. This method of peeling is rapid, easily mechanized, and results in fairly low peeling loss.

Lye Peeling. Lye peeling has been found especially satisfactory for peeling sweet potatoes and is used generally by canners. Woodroof and Cecil (1948) recommended peeling cured Puerto Rico potatoes in 10% lye at 212°F (100°C) for 8–10 min, replacing the alkali at the rate of 1 lb (0.454 kg) for each bushel of potatoes peeled. Uncured potatoes required only about one-half the time and slightly less than half the alkali for peeling. The peeling time was reduced by more than 10% by the use of trisodium phosphate, tetrasodium phosphate, or other detergents or surface-active agents. Discoloration was prevented by preheating the unpeeled potatoes to 180°F (82°C) and/or by dipping freshly lye-peeled potatoes in a 2% citric acid solution. Apparently the degree of curing has little effect on the depth of lye penetration; the increased time required for cured potatoes was due to the cortex being harder and tougher. Even when potatoes were left in lye solution until cooked, no lye penetrated beyond the cortex except along the fibers.

Data in Table 5.1 show that the peeling and trimming losses during lye peeling varied from 34.4% with very small cured potatoes to 14.9% with large potatoes, other conditions being equal. Practically the same ratio was obtained from steam-pressure peeling, indicating that the smaller the potatoes the greater the peeling loss.

Data in Tables 5.2 and 5.3 show that the peeling loss varied with the weight (size) of uncured and cured sweet potatoes, when all other conditions were the same. With uncured potatoes, average peeling loss ranged from 18.3% for 3-oz (85-g) potatoes to 10.1% for 18-oz (510-g) potatoes. With

Table 5.1. Effect of Size of Cured No. 1 Puerto Rico Sweet Potatoes on Peeling and Trimming Loss During Lye Peeling^a

| Size of sweet potatoes | | | Peeling and trimming losses (%) |
|------------------------|---------|------------|---------------------------------|
| (in.) | (cm) | (size) | |
| 1 to 1 1/2 | 2.5–4 | very small | 34.4 |
| 1 1/2 to 2 1/2 | 4–6.4 | small | 26.3 |
| 2 1/2 to 3 1/2 | 6.4–9 | medium | 22.3 |
| 3 1/2 to 4 1/2 | 9–11.5 | large | 16.9 |
| 4 1/2 to 5 1/2 | 11.5–14 | jumbo | 14.9 |

Source: Woodroof and Cecil (1948).

^a10% lye at 210°F (99°C) for 10 min.

Table 5.2 Influence of Weight of Uncured No. 1 Puerto Rico Sweet Potatoes on Peeling Loss during Lye Peeling^a

| Average weight per potato | | Average peeling loss (%) |
|---------------------------|-----|--------------------------|
| (oz) | (g) | |
| 3.0 | 85 | 18.5 |
| 5.0 | 142 | 16.8 |
| 7.0 | 199 | 14.2 |
| 9.0 | 255 | 12.7 |
| 12.0 | 340 | 12.0 |
| 18.0 | 510 | 10.1 |

Source: Woodroof and Cecil (1948).
^a10% lye solution at 210°F (99°C) for 5 min.

cured potatoes, peeling losses ranged from 24.0 to 53.9% and trimming losses ranged from 2.7 to 9.1% depending upon the size.

Data in Table 5.4 show that the alkali required to peel 1000 lb (454 kg) of sweet potatoes in a draper-type scalding with closed coils varied from 4.8 lb (2.2 kg) for freshly dug field-run potatoes to 17.5 lb (8 kg) for cured very small potatoes, and that losses of alkali by dumping were as high as 9.5 lb (4.3 kg). The amount of alkali used varied with the size of the potatoes and whether they were freshly dug or cured. The total amount of lye required to peel 1000 lb (454 kg) of freshly dug potatoes was 6.4 lb (2.9 kg); that required for the same quantity of cured jumbo potatoes was 14.2 lb; and that required for cured small potatoes was about 27.8 lb (10.4 kg). In these studies, on the average, about 66% of the total alkali used was used

Table 5.3. Influence of Weight of Cured Sweet Potatoes on Peeling and Trimming Losses Under Commercial Conditions during Lye Peeling^a

| Sweet potatoes | | | Processing loss | | Yield of finished product (%) |
|----------------|-----------|------------|-----------------|--------------------------|-------------------------------|
| (kg) | (lb) | (size) | Peeling (%) | Washing and trimming (%) | |
| 394,571 | 1,057,831 | Very small | 53.9 | 9.1 | 37.0 |
| 27,578 | 73,935 | Small | 33.6 | 8.0 | 58.4 |
| 7,637 | 20,475 | Medium | 29.7 | 6.0 | 64.3 |
| 11,548 | 30,960 | Large | 29.0 | 4.8 | 66.2 |
| 2,551 | 6,840 | Jumbo | 24.0 | 2.7 | 73.3 |

Source: Woodroof and Cecil (1948).
^a10% lye solution at 210°F (99°C) for 10 min.

Table 5.4. Alkali Required for Peeling 1000 lb (373 kg) of Sweet Potatoes under Commercial Conditions in a Draper-Type Scalder with Closed Coils

| Grade of potatoes | Alkali required | | | | | |
|-----------------------|-----------------|------|--------|------|-------|------|
| | For peeling | | Losses | | Total | |
| | (lb) | (kg) | (lb) | (kg) | (lb) | (kg) |
| Freshly dug field run | 4.8 | 1.8 | 1.6 | 0.6 | 6.4 | 2.4 |
| Cured ^a | | | | | | |
| Very small | 17.5 | 6.5 | 9.5 | 3.5 | 27.3 | 10.4 |
| Small | 14.6 | 5.5 | 5.2 | 1.9 | 19.3 | 7.4 |
| Medium | 12.7 | 4.7 | 5.1 | 1.9 | 17.3 | 6.6 |
| Large | 11.1 | 4.1 | 4.9 | 1.8 | 16.0 | 6.0 |
| Jumbo | 9.3 | 3.5 | 4.9 | 1.8 | 14.2 | 5.3 |

Source: Woodroof and Cecil (1948).

^aSee Table 5.1 for dimensions of various size designations.

for peeling and the remainder was wasted during the operation or dumped when the solution became unusable. The fact that wide variations occurred from day to day in the total amount of alkali used, without being reflected in the percentage of potatoes canned, indicated a possibility for greater economy in lye consumption.

The amount of alkali required to make up lye solutions from 1 to 10% in peeling vats of six different sizes is shown in Table 5.5. Calculations may easily be made for vats of any size. To use Table 5.5, determine the capacity of the vat in cubic feet when filled to the desired level, then multiply by 7.09 to determine the capacity in gallons. In the left-hand column, find the lye concentration desired, then follow the horizontal line to the column indicating the capacity of the tank; this figure is the pounds of lye needed. For example, to make 360 gal (1637 liter) of 5% lye solution, 158 lb (71.7 kg) of alkali are required.

Exploding. Exploding in a 25- to 27-in (63.5 to 69-cm) vacuum, following heating to 240–250°F (116–121°C) for 2–3.5 min in a retort, may be used for peeling sweet potatoes and other fruits and vegetables. The method is a modification of the steam pressure method but is more rapid and expensive, since equipment for supplying both pressure and vacuum is required.

High-Pressure Steam Peeling

A batch high-pressure steam peeler with regulated pressure control was developed to take advantage of steam peeling while avoiding the difficulties encountered with the conventional steam peeler. This system effectively sep-

Table 5.5. Alkali Required to Make Up Solutions from 1 to 10% in Peeling Vats of Six Sizes

| Desired lye concentration (%) | Capacity of peeling vats (gal) ^a | | | | | |
|-------------------------------|---|---------------------|---------------------|---------------------|---------------------|---------------------|
| | 360 | 384 | 408 | 432 | 456 | 480 |
| | <i>1636.6</i> | <i>1745.7</i> | <i>1854.8</i> | <i>1963.9</i> | <i>2073</i> | <i>2182.1</i> |
| 1 | 30 <i>13.6</i> | 32 <i>14.5</i> | 34 <i>15.4</i> | 36 <i>16.3</i> | 38 <i>17.3</i> | 40 <i>18.2</i> |
| 2 | 61 <i>27.7</i> | 65 <i>29.5</i> | 69 <i>31.3</i> | 74 <i>33.6</i> | 78 <i>35.4</i> | 82 <i>37.2</i> |
| 3 | 94 <i>42.2</i> | 99 <i>45.0</i> | 105 <i>47.7</i> | 112 <i>50.9</i> | 118 <i>53.6</i> | 124 <i>56.3</i> |
| 4 | 125 <i>56.8</i> | 134 <i>60.8</i> | 142 <i>64.5</i> | 150 <i>68.1</i> | 159 <i>72.2</i> | 167 <i>75.8</i> |
| 5 | 158 <i>71.7</i> | 169 <i>76.7</i> | 179 <i>81.3</i> | 190 <i>86.3</i> | 201 <i>91.3</i> | 211 <i>95.8</i> |
| 6 | 192 <i>87.2</i> | 204 <i>92.6</i> | 218 <i>99.0</i> | 230 <i>104.4</i> | 244 <i>110.8</i> | 256 <i>116.2</i> |
| 7 | 226 <i>102.6</i> | 241 <i>109.4</i> | 257 <i>116.7</i> | 272 <i>123.5</i> | 287 <i>130.3</i> | 302 <i>137.1</i> |
| 8 | 262 <i>119.0</i> | 279 <i>126.7</i> | 296 <i>134.4</i> | 314 <i>142.6</i> | 331 <i>150.3</i> | 349 <i>158.5</i> |
| 9 | 298 <i>135.3</i> | 317 <i>143.9</i> | 337 <i>153.0</i> | 357 <i>162.1</i> | 376 <i>170.7</i> | 396 <i>179.8</i> |
| 10 | 334 <i>151.6</i> | 356 <i>161.6</i> | 378 <i>171.6</i> | 401 <i>182.1</i> | 423 <i>192.0</i> | 445 <i>202.0</i> |

^aItalicized headings are vat capacities in liters, and italicized table values are corresponding amounts of alkali required in kilograms. Table values in roman type are gallons of alkali.

arates the peel from the flesh for a variety of fruits and vegetables (Burkhardt *et al.* 1970).

Peeling of large volumes of vegetables can be accomplished mechanically, chemically, or by use of scalding water or high-pressure steam. High-pressure steam peeling offers distinct advantages in some instances in that it can be easily automated and precisely controlled to minimize peeling losses. This process also avoids chemical contamination of the product itself and reduces the pollution problem associated with chemical peeling.

Experience with sweet potatoes in this type of peeler has demonstrated that the larger and broken potatoes have a tendency to literally explode in the peeling process. Another phenomenon that occurs is the blowout of small vascular bundles from the flesh, leaving the appearance of wormlike holes.

Factors Affecting Peeling Process. The criteria for evaluating a peeling process are the effectiveness of removing the peel, the quality of the flesh remaining, and the product loss due to peeling. The end result is primarily

a function of the temperature-time relationship to which the fruit or vegetable has been exposed. The mechanisms that cause the skin to be separated from the flesh when exposed to high temperatures are not clearly defined for all products. However, it appears that both a physical phenomenon and a biochemical reaction occurring within the product result in the separation process.

It is assumed that the physical phenomenon that aids in the peeling process is the internal pressure that is created within the product when exposed to a high-pressure and temperature environment. This internal pressure is the result of vaporizing the liquids beneath the skin surface by raising them to above their boiling point. As soon as the chamber pressure is released, however, the pressure surrounding the product is lower than the internal pressure of the product. This pressure differential creates an internal force that acts against the skin, physically forcing it away from the flesh.

Skin removal is facilitated by a softening of the cell tissue just beneath the skin layer. This action is probably caused by several factors associated with the heat, such as the hydrolysis of carbohydrates and degradation of pectic substances within the cells.

Another aspect that needs to be considered when evaluating a peeling process is what effect the process has on the quality of the product. The quality of a product can be broken down into three main categories—texture, appearance, and flavor. These categories can be further subdivided into many indices, for example, firmness, which will be used to evaluate the quality of the texture, and color, which will be used to evaluate the quality of appearance. Flavor is not considered to be greatly affected by high-pressure steam peeling and therefore will not be discussed. Firmness of many products is considered to be affected by changes in cellular organization, usually involving permeability changes, and/or activity of the pectic enzyme systems. Similarly, the polyphenolase system, present in many vegetables, is responsible for discoloration or “browning” following peeling.

Browning Reaction. Most vegetables contain both the enzyme system (polyphenolase) and substrates (phenolic compounds) required for browning; thus, they are susceptible to darkening when cellular organization is disrupted. Since there is very little that can be done with respect to the oxidizable substrate, attention will be focused on the behavior of the enzyme and what needs to be done to inhibit or inactivate it.

When a product is heated to a temperature somewhere between the approximate range of 140 and 190°F (60 and 88°C), the normal respiratory processes become inactive, whereas the polyphenolase system becomes more active. It is assumed that subjection to such temperatures permits reaction of the enzyme and substrate and thus completes the biochemical reaction resulting in browning. The phenolase enzyme can be inactivated if its temperature is raised to approximately 200°F (93°C). Thus a very precise

time-temperature relationship in the area subject to browning must exist if discoloration is to be avoided.

The browning phenomenon is somewhat different with sweet potatoes in that browning occurs primarily in the cambial area, located about $\frac{1}{8}$ in. (0.32 cm) beneath the surface of the potato. Thus in sweet potatoes, browning can be prevented by peeling deeply enough to remove the cambial area or by effecting heat penetration to ensure inactivation of the phenolase system in this area.

Softening Reaction. When heat is applied to plant foods many changes occur. When heat is applied for a brief period of time, as during high-pressure steam peeling, wilting of the tissue results, with a loss in rigidity due to reduced "turgor pressure." The softness of texture that results from steam peeling varies with the particular fruit or vegetable. For most products, this is not a serious problem.

Equipment Components. The high-pressure steam peeler described by Burkhardt *et al.* (1970) consists basically of four subsystems: the peeling system, the weighing and dumping system, the high-pressure steam system, and the electrical system.

Peeling System. The peeling system is the heart of the machine. It is mounted between two 5.5-in. (14-cm) by 15-in. (38-cm) I-beams that, together with the leg mountings and tie-rods, constitute the major portion of the machine framework. The peeling chamber consists of two telescoping horizontal cylinders with a shaft on both ends. The shaft on the inner cylinder is mounted by means of two thrust bearings to the one I-beam. The shaft on the outer cylinder passes through a rotating flange containing an idler bearing and is then connected to a hydraulic piston, which is mounted to the other I-beam. The shaft itself contains two thrust bearings, which allow the chamber to rotate independently of the piston. The idler bearing in the rotating flange allows the piston to move back and forth through the I-beam mounting.

Longitudinal movement of the piston is provided by a hydraulic pump. Direction of travel is controlled by a magnetic valve. The inner cylinder has part of its cylindrical surface cut away and serves as a basket that catches, holds, and dumps the product being peeled. It does not move longitudinally.

The outer cylinder moves longitudinally by means of the hydraulic piston. When the piston is fully extended, the outer cylinder completely encompasses the inner cylinder, closing the peeling chamber. The chamber is sealed by an O-ring seated in a groove on the inner cylinder.

Proper alignment of the outer cylinder with the inner cylinder is essential to create a seal to maintain the high-pressure steam in the chamber. The alignment is provided by four guide rods, which are anchored to a flange

on the inner cylinder, pass through Teflon insert-bearings in flanges at both ends of the outer cylinder, and terminate in the rotating flange on the hydraulic piston mounting. These rods also ensure that the rotation of both cylinders will be exactly the same.

Rotation is provided by a gear reduction motor and controlled by a magnetic clutch-brake, both of which are mounted on one of the I-beams. Rotation is required to permit automatic filling and emptying and to provide some agitation so that all parts of the product are exposed directly to the steam.

Weighing and Dumping System. An automatic hopper is located directly above the inner cylinder of the peeling chamber. Its purpose is to meter the product and to fill the compartment at the proper time.

High-Pressure Steam and Electrical System. As soon as the steam is exhausted from the chamber and the pressure returns to zero, the low-pressure mercury switch completes a circuit actuating relay 5 and stops the rotation of the drum. This circuit, in conjunction with the limiting switch down and closed, opens the chamber, dumping the product into a holding bin. The chamber then turns one-half of a revolution so that the opening is in the upward position ready to receive the next batch of produce from the hopper-dumper and begin its next cycle.

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