

## Chapter 8

## CUCUMBERS

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## I. INTRODUCTION

## A. Historical Development of the Crop

The cucumber (*Cucumis sativus* L.) is thought to have originated in Africa<sup>1</sup> or in China, India, or the Near East<sup>2-4</sup> with domestication occurring later throughout Europe. *Cucumis sativus* var. *hardwickii* (Royle) Kitamura, a weedy or ancestral form of cucumber, is found in the Himalayan foothills of India. That fact has been cited as evidence that the cucumber originated there and was subsequently brought to the other areas during domestication.<sup>4</sup>

Records indicate that cucumber was used for food in ancient Egypt and by the Greeks and Romans 3000 to 4000 years ago.<sup>5</sup> The cucumber was grown in France as early as the 9th century and in England as early as the 14th century. Christopher Columbus is said to have brought cucumber seeds to the Americas. Native tribes were growing it from Florida to Canada in the early 16th century.

Cucumber is now grown throughout the world using field or greenhouse culture, and is used in a number of distinct forms. The major types are the American pickling and fresh-market types; the Dutch gherkin and greenhouse types, the German Schalgurken type, the Mideast Beit Alpha type, and the Japanese fresh-market (burple) type.

While all commercially important cucumbers belong to the same species and will cross with one another, the various types have been selected for specific purposes. For example, fresh-market cucumbers, sometimes referred to as slicers, have been selected for a tough skin which will hold up well in marketing channels but for that reason, is unsuitable for the manufacture of pickles. Further, fresh-market cucumbers have a longer length-to-diameter ratio than pickling cucumbers, a factor in selecting glassware for packing whole pickles. Carpel separation in fresh market cucumbers is relatively unimportant but extremely important in pickling cucumbers. Therefore, only those types that have been selected for tender skin, good interior, and the typical pickling cucumber shape should be used for processing into pickles.

## B. Cultivar Development

Although cucumber has been cultured for thousands of years, the earliest records indicate that cultivars were first developed in Europe in the 1700s. The first cultivars used in the U.S. were brought from Europe, and included Early Short Prickley, Long Green Turkey, Smyrna, Roman, and White Spined.<sup>1</sup> Additional cultivars sold in the U.S. were China Long in 1862 and Chicago Pickling in 1888.<sup>6</sup> Beginning in 1880, there was interest in cultivar development by and for American growers. The number of cultivars increased from that point, providing better adapted as well as new types of cucumbers for the American market.

Fruit shape and color were the major traits improved in the new cultivars developed in the first few decades of the 1900s.<sup>7-24</sup> Model, introduced in 1946 with good fruit shape and adaptation to the southern production regions of the U.S., is a good example of that trend. Emphasis began to be placed on disease resistance in 1937 with the introduction of the cucumber mosaic virus-resistant cultivar Shamrock. With the introduction of cultivars with scab (*Cladosporium cucumerinum* Ellis & Arthur) and downy mildew (*Pseudoperonospora cubensis* (Berk. & Curt) Rostow) resistance, additional disease resistances were combined in subsequent cultivar releases. In 1955, resistance to scab and cucumber mosaic virus (CMV) were combined in the line Wisconsin SMR-12. Additional resistances were identified, and eventually combined into the lines Sumter, with resistances to 7 diseases, and Wisconsin 2757, with resistances to 9 diseases — scab, CMV, bacterial wilt (*Erwinia tracheiphila* (E. F. Smith) Holland), angular leaf spot (*Pseudomonas lachrymans* (E. F. Smith and Bryan) Carsner), anthracnose (*Colletotrichum lagenarium* (Ross.) Ellis & Halst), downy mildew, powdery mildew (*Sphaerotheca fuliginea* (Schl. ex Fr.) Poll.), target leaf spot (*Corynespora cassicola* (Berk. & Curt) Wei), and fusarium wilt (*Fusarium oxysporum* (Schlecht.) Snyder & Hans f. sp. *cucumerinum* Owen) (Table 1).

**Table 1**  
**IMPORTANT STEPS IN THE GENETIC IMPROVEMENT OF CUCUMBER**  
**IN THE U.S.**

Cultivar or line	Developer or seed source	Year introduced	Noteworthy traits(s)
<b>Improvement of disease resistance</b>			
Shamrock	Iowa State College, Ames	1937	CMV
Maine No. 2	Maine Agricultural Experiment Station	1939	Scab
P.R. 39	Puerto Rico Agricultural Experiment Station	1944	DM
Wisconsin SMR 12	University of Wisconsin, Madison	1955	Scab, CMV
Pixie	South Carolina Agricultural Experiment Station	1963	DM, PM, Anth
Sumter	South Carolina Agricultural Experiment Station	1973	DM, PM, Anth, ALS, CMV, Scab, WMV
Wisconsin 2757	U.S.D.A. University of Wisconsin	1982	DM, PM, Anth, ALS, CMV, Scab, TLS, BW, FW
<b>Improvement of other traits</b>			
Midget	Minnesota Agricultural Experiment Station	1940	Dwarf-determinate habit
Burpee Hybrid	W. Atlee Burpee Co.	1945	Mon-Hyb, CMV, DMV
Model	Associated Seed Growers	1946	Fruit shape
MSU 713-5	Michigan Agricultural Experiment Station	1960	Gyn
Spartan Dawn	Michigan Agricultural Experiment Station	1962	Gyn-Hyb, CMV, Scab
Littleleaf	University of Arkansas	1980	Multibranched habit
Castlepick	A. L. Castle & Co.	1983	Dwarf-determinate, Gyn-Hyb

*Note:* CMV = cucumber mosaic virus resistance; DM = downy mildew resistance; Scab = scab resistance; PM = powdery mildew resistance; Anth = anthracnose resistance; ALS = angular leafspot resistance; WMV = watermelon mosaic race 2 resistance; TLS = target leafspot resistance; BW = bacterial wilt resistance; FW = fusarium wilt resistance; Mon = monoecious sex expression; Gyn = gynoecious sex expression; Hyb = hybrid.

Meanwhile, progress was made in the improvement of other traits such as sex expression and plant habit. Midget was a dwarf-determinate cultivar introduced in 1940 (Table 1). The dwarf-determinate character was not used extensively, however, until later with the introduction of Castlepick, which was a semidwarf cultivar with determinate flowering habit. Monoecious hybrids were introduced in 1945, but seed was too expensive to permit wide use. Development of gynoecious sex expression permitted hybrids to be produced economically.<sup>25</sup> Spartan Dawn was the first (1962) gynoecious hybrid released for industry use, and the breeder used the gynoecious inbred 713-5 as a parent. The gynoecious character was incorporated into Wisconsin 2757 in addition to its multiple disease resistance.<sup>26</sup> Still needed are cultivars with resistance to *Rhizoctonia* fruit rot (*Rhizoctonia solani*), gummy stem blight (*Didymella bryoniae*), watermelon mosaic virus race 1, and zucchini yellow mosaic virus. Additional efforts will undoubtedly improve fruit quality, yield, earliness, and adaptation to the production environments of the U.S. even further. Dwarf plant types (such as the compact mutant) for high density plantings,<sup>27</sup> or multibranching types (such as littleleaf) for simultaneous fruiting<sup>28</sup> may provide needed improvement in fruit yield for once-over harvest systems.

### C. Production Methods

Soil for cucumber production should be well drained to prevent root and fruit rots. Soil with very high organic content should be avoided because of the difficulty of removing adhering particles from the fruit. Sandy soils warm up faster in the spring but also require irrigation and frequent applications of fertilizer during the growing season.

Chemical analysis of the soil before planting is a valuable aid for the grower, permitting the adjustment of pH and fertility for higher fruit yields. Dolomitic lime should be applied to the soil to provide a pH of 6.0 to 6.5. Nitrogen should be applied at a rate of about 112 kg/ha for multiple-harvest systems, with about 65 to 70% applied before planting and the remainder at about first bloom. For once-over harvest systems, nitrogen should be applied at a rate of 80 to 90 kg/ha, all before planting. Phosphorus, depending on soil content, should be applied at 0 to 40 kg/ha, all before planting. Likewise, all of the potassium should be applied preplant at rates up to 75 kg/ha.<sup>29,30</sup>

The cucumber is a warm season crop and is injured or killed by temperatures of 6°C or lower. Optimum temperatures are 25 to 32°C and fruit set may be adversely affected at temperatures above 32°C. Little or no growth of seedlings occurs below 16°C.<sup>31</sup> Therefore, it does no good to seed until the soil warms above that temperature. Rapid germination and seedling emergence is favored by temperatures in the 20 to 27°C range. Low temperature injury to the fruits will be discussed under raw fruit storage.

Row spacing for multiple harvest is usually dictated by the way the grower's equipment is set up and varies from 0.9 to 1.8 m with 1.1 to 1.5 m most common. Within-row spacings should be adjusted to result in 49,000 to 62,000 plants/ha.<sup>29</sup> For once-over harvest, plant populations of 112,000 to 225,000 plants/ha are required.<sup>32</sup> Raised beds are useful in areas where heavy rainfall causes drainage problems.

Deficiency of moisture results in reduced yields and misshapen fruits.<sup>33</sup> For best quality, cucumbers require moisture in 5- to 7- day intervals. In arid regions, irrigation is provided for every crop. However, growers in humid areas often depend upon rainfall to water their crops. Because rain almost never falls evenly enough to meet the entire needs for a cucumber crop, supplemental irrigation is very important. The most critical needs for moisture begin at flowering and continue throughout harvesting. On the other hand, excessive moisture can result in waterlogged soils, which are detrimental to cucumber plant growth. Also, rainfall discourages bee activity which often results in poor pollination.

Use of herbicides together with cultivation will provide good weed control in multiple-harvest cucumbers. However, cultivation of once-over harvest cucumbers is difficult and the grower must rely on herbicides to a great extent.

Other pesticides should be used at the first sign of the pest, detected by frequent scouting of the grower's field. Spring crops in the U.S. ordinarily require infrequent insecticides and fungicides. However, as insects and pathogens build up later in the season, more pesticides are required. Crops grown in summer or fall, especially in the southern U.S., require weekly applications of pesticides. In the case of the pickleworm (*Diaphania nitidalis*), prevention is absolutely required since there is a zero tolerance level for it in cucumbers intended for processing.

Conventional cucumbers require pollination for fruit set and development. The most important insect pollinators are honey bees, both wild and domestic.<sup>34</sup> Many experiment stations recommend that 2 or 3 strong colonies of bees per hectare be placed within 100 m of the edge of the field, about the time of full bloom. Because the number of seeds in cucumber fruits does not exceed the number of pollen grains applied to the stigma,<sup>35</sup> adequate pollination is necessary for large numbers of well-formed cucumbers.<sup>36</sup> Under otherwise favorable conditions cucumber flowers opened at 14.4 to 15.6°C, anther dehiscence, nectar secretion, and bee activity occurred above 16.7°C, and pollen tubes developed at temperatures above 21.0°C.<sup>37</sup> Under optimum conditions, 4 days were required for pollen tubes to reach the base of the fruit. For the fruit to reach grade 3 pickling size (38 to 51 mm diameter) 3 to 6 more days were required.

Harvesting of cucumbers in a multiple harvest system begins as soon as marketable fruits are present in sufficient numbers, and before oversized fruits develop. In the southern U.S., that is usually 6 to 8 days after the appearance of pistillate flowers. Harvesting is largely

done by hand because of the ready availability of workers, and because machines developed for multiple harvest do not do as good a job. In once-over harvest systems, machines have been developed to do a satisfactory job but the timing of harvest is important for high yield. For best results, harvesting should be delayed until 5 to 20% of the fruits exceed 51 mm in diameter.<sup>38</sup>

## II. FACTORS INFLUENCING QUALITY OF CUCUMBERS FOR PROCESSING

Yield and earliness of a cultivar are important to the grower and processor, but those traits do not directly affect the quality of the processed fruits. Although it has been suggested that the fruits from the first harvest of the cucumber plants have a smaller length/diameter ratio (L/D) a publication on that subject shows no evidence for the shortened L/D.<sup>39</sup> Fruits with short L/D are less useable for certain packs of whole cucumbers. Vine characteristics are important to the plant breeder who is developing a cultivar adapted to particular production systems. Tall (long) indeterminate types are used for multiple-harvest (hand or machine) systems. Dwarf-determinate types are more suited for once-over harvest, or for systems where it is not possible to harvest more than the usual 9 to 20 times.

Sex expression is related to fruit quality because gynoecious cultivars tend to produce a heavy load of fruits before the plant has attained a large size. The extra fruits are often not well filled out as a result, and often must be discarded as nubs and crooks in the grading shed. Also, cultivars that are hermaphroditic, andromonecious, gynomonocious, or trimonocious have perfect flowers that develop into spherical rather than oblong fruits. Spherical fruits are not useable for processing because they usually have a large seedcell, making them susceptible to brine storage defects such as bloating and soft centers. Also, spears and chips made from fruits with large seed cells fall apart or collapse more easily.

Disease resistance is important to the production of high quality fruits for processing. Anthracnose, cucumber mosaic virus, and scab can cause lesions on the fruits if the disease becomes severe on the foliage. In addition, fungi such as *Rhizoctonia solani* and *Pythium* spp. attack the fruits directly, reducing the yield and causing some of the fruits to be blemished. As discussed previously, resistance to most of the fruit-damaging diseases is available in adapted cultivars with the exception of the fruit rots caused by *R. solani* and *Pythium* spp.

Stress resistance can be important to the quality of the cucumber fruits produced for processing. In cultivars used for processing into pickles, it is important to have resistance to bloating and to soft centers. Resistance to balloon, lens, and honeycomb bloating can be evaluated in a number of ways. The easiest method is to evaluate the fruits on a subjective scale for the difficulty in tearing the carpels apart using the thumb test on fruits cut into longitudinal halves. A test that provides better estimates of bloater resistance makes use of 19 l (5 gal) pails filled with cucumbers and brine.<sup>40</sup> The brine is saturated with carbon dioxide to encourage bloating. The cultivars being tested will then show obvious bloating if they are susceptible.

Fruit firmness and skin toughness are also important considerations in the development of cultivars suited to processing. Fruits should be firm, but the skin should be thin and tender. These characters can be measured using a USDA fruit pressure tester. The amount of force required to puncture the fruit will be high in firm fruits. To test for tender skin, a desirable trait, the test should be run on fruits with and without the skin. The punch test reading with the fruit peeled should be close to the reading with the skin intact for tender skin. An added advantage is provided with the punch test because there is a correlation between fruit firmness and balloon bloater resistance.<sup>41</sup> Seed cell size and seediness are important considerations for cucumber fruits being used to make chips and spears, because

large seedcells with large seeds tend to fall apart when the fruits are sliced. Seedcell size can be selected during cultivar development and has been progressively reduced with new releases. Heritability has been estimated to be 0.49, considered to be a moderate level.<sup>42</sup>

Numerous harmful insects must be controlled if one is to produce cucumbers successfully. However, pollinating insects such as honeybees and bumble bees must be spared. Genetic resistance, when available, should be utilized. Insecticides, when used, should be applied in the afternoon when bee activity is low, and when the prevailing winds are blowing away from areas where colonies of bees are kept.

#### **A. Harvesting and Handling of Raw Product**

In anticipation of reduced availability and increase cost of harvest labor, individuals at universities and private companies began 20 to 25 years ago to develop machines that would harvest pickling cucumbers. Most of the machine research at Michigan State University has been directed toward those that harvest once-over. The most recent improvement has been the "threshing concept" which has been incorporated into a once-over harvester.<sup>43</sup> It is estimated that 50% of the Michigan crop is currently harvested by once-over machines, although several years ago, the percentage was higher.<sup>44</sup> Improved postharvest handling of cucumbers is leading to a resurgence of interest in machine harvesting in that state.

The North Carolina program has been aimed at development of a multiple-pick machine. Tests indicate that, with an experienced operator, the multiple-pick machine compares quite favorably to hand-pick.<sup>45</sup> The continued availability of harvest labor has kept interest in machine harvesting at a low level. Another complicating factor has been the reluctance of large machinery manufacturers to become involved in the development of harvesters with limited opportunity for sales. On the other hand, smaller manufacturers usually lack the resources to solve production problems and to provide local parts and repair services.

At present, both North Carolina and South Carolina have almost no mechanically harvested cucumbers. Georgia, however, has several hundred hectares of pickling cucumbers that are harvested by once-over machines.<sup>46</sup>

It is important that cucumbers intended for processing be handled carefully, because damage to the outside of the fruits reduces the attractiveness of the packed product, and damage to the inside of the fruits increases the likelihood that they will bloat during storage. It has been estimated that up to 50% of the fruits were damaged (smashed, cut, or bruised, or soil ground into the skin) by once-over mechanical harvesting.<sup>47</sup> Rough handling of fruit such as that sometimes prevalent in harvesting and grading can induce bloating.<sup>48</sup> Visible external damage was associated with the distance the fruits were dropped, and bloater damage was associated with the number of times the fruits were dropped. Large fruits were more resistant than small cucumbers to skin fracture.<sup>49</sup> Fruits of Chipper were more resistant to skin fracture than those of Pioneer.

Cucumbers are typically delivered by growers to receiving stations maintained by the contracting pickle processing company. At that location, the cucumbers are graded (Figure 1) and the growers are paid according to grade. The number of marketable grades vary according to the needs and desires of individual packers and may be as few as three or as many as seven or more. Some states of the U.S. (e.g., North Carolina) use one set of grades for all companies. Others allow individual companies to establish and maintain their own system. Personnel at the receiving stations accumulate cucumbers by marketable grades and dispatch them to the pickle factories by truck. Cucumbers should be kept cool by storing in a shaded area while awaiting enough for a truckload for short distance shipping. A commonly-used container at receiving stations is the 705 l (20 bushel) bin (Figure 2).

Raw cucumbers must be handled promptly. If they are to be transported several hundred kilometers, they should be hydrocooled (Figure 3) to reduce internal temperature of the cucumber to 7 to 10°C. That will do much to maintain the quality of the raw product that

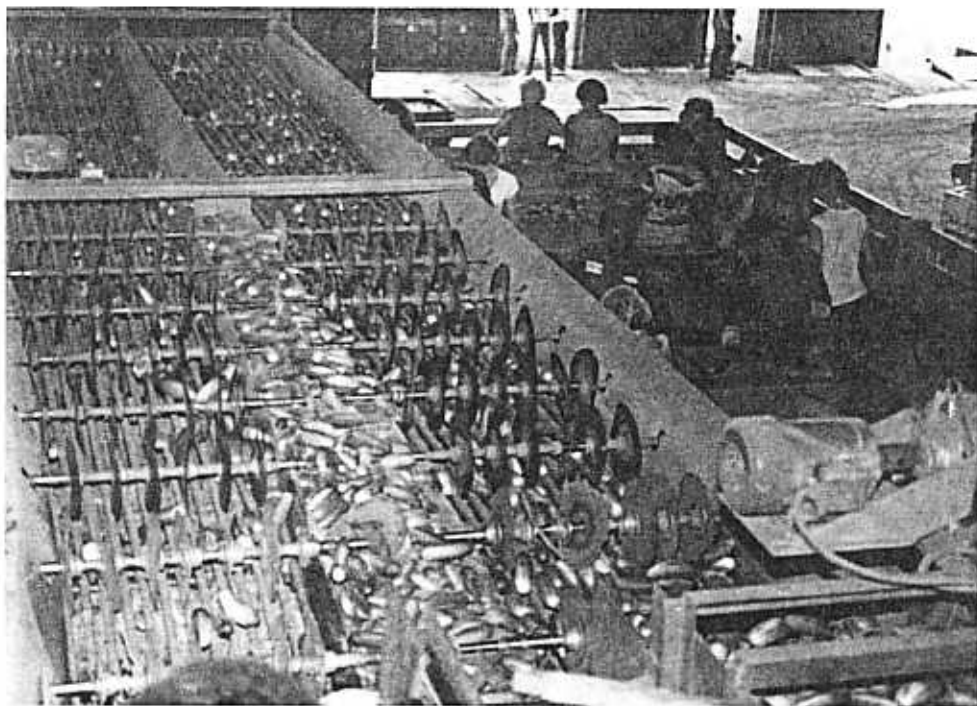


FIGURE 1. Grading of pickling cucumbers. Workers on the right are picking out nubs, crooks, and other undesirable objects.

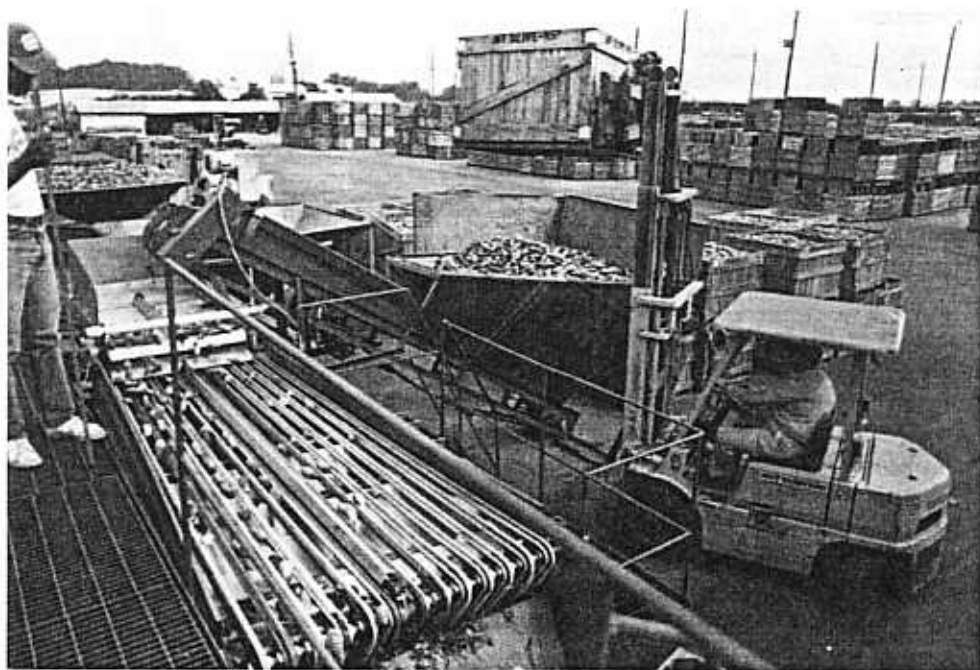


FIGURE 2. A 705-1 (20 bushel) bin of cucumbers being dumped into a hopper located at a pickle processing plant. Cucumbers are then conveyed onto grading equipment where they are sized.

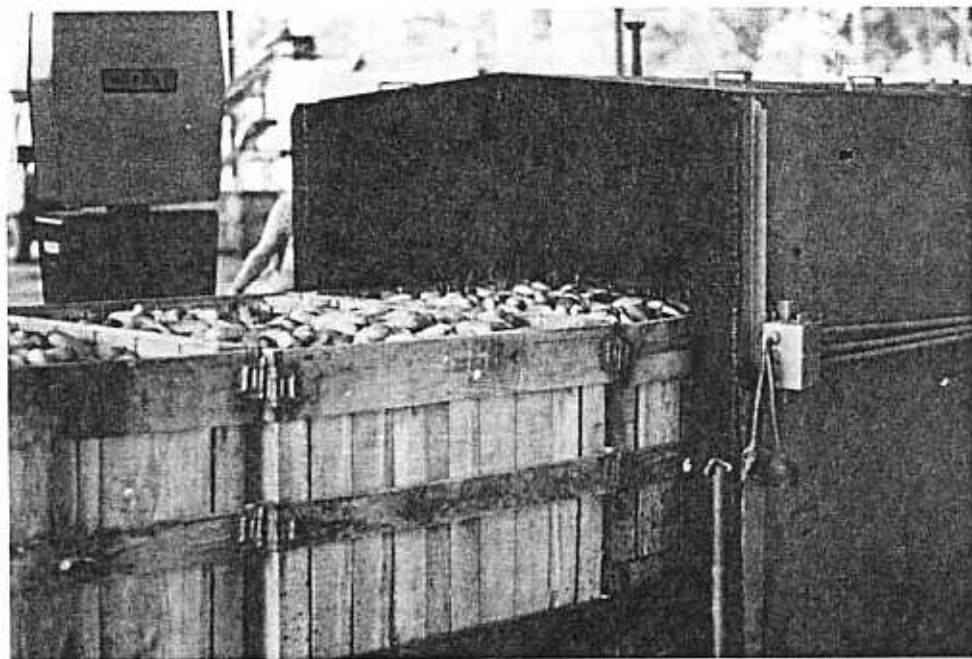


FIGURE 3. Cucumbers in 705-1 (20 bushel) bins entering a hydrocooler. The water in the hydrocooler is cooled by combined mechanical refrigeration and ice. The speed at which cucumbers move through the hydrocooler can be adjusted to result in the reduction of internal temperature to the range of 7 to 10°C.

reaches the pickle processing plant. In lieu of hydrocooling, cucumbers are sometimes transported at night in trucks that allow ambient air to flow through the load.

After the cucumbers arrive at the processing plant, they are placed either in fresh pack channels including raw product storage or in brine storage (Figure 4). Presently, it is estimated by Pickle Packers International that 40% of cucumbers processed in the U.S. are brined, 40% are fresh packed and 20% are refrigerated.<sup>50</sup>

### **B. Refrigerated Storage**

Fresh cucumbers can be held in refrigerated storage to extend the fresh-pack season, to "level-out" the flow of fruit into the processing plant during periods of high field production, when the pickle plant might be closed for the weekend or a holiday, or when the raw fruit must be transported great distances from the field to the processing plant. Small cucumbers (under 33 mm diameter) could be held for 6 days and larger cucumbers (38 to 51 mm diameter) for 9 days in regular refrigerated storage at 1.1 to 4.4°C, provided the fruit were not washed.<sup>51</sup> Washing of fruit reduced the storage life to half that of the unwashed fruit. Controlled atmosphere storage at similar temperatures extended the storage life for small cucumbers by 2 weeks and for larger cucumbers by 3 weeks. The best combination of the test conditions was 1.1°C at 5% carbon dioxide and 5% oxygen. The authors emphasized, however, that the fruit deteriorated rapidly after removal from storage.

Storage experiments involving 5 temperatures and 4 relative humidities were conducted in which pickling cucumbers were examined for weight loss, growth of 8 microbial groups, and activities of 2 enzyme systems (pectinolytic and cellulolytic). In general, microbial populations out of the 8 groups increased rapidly at the higher temperatures (over 21°C) and humidities (over 70%) treatments. Moisture loss by cucumbers was rapid at all combinations of high temperatures and low humidities. Results suggested that the best storage temperature



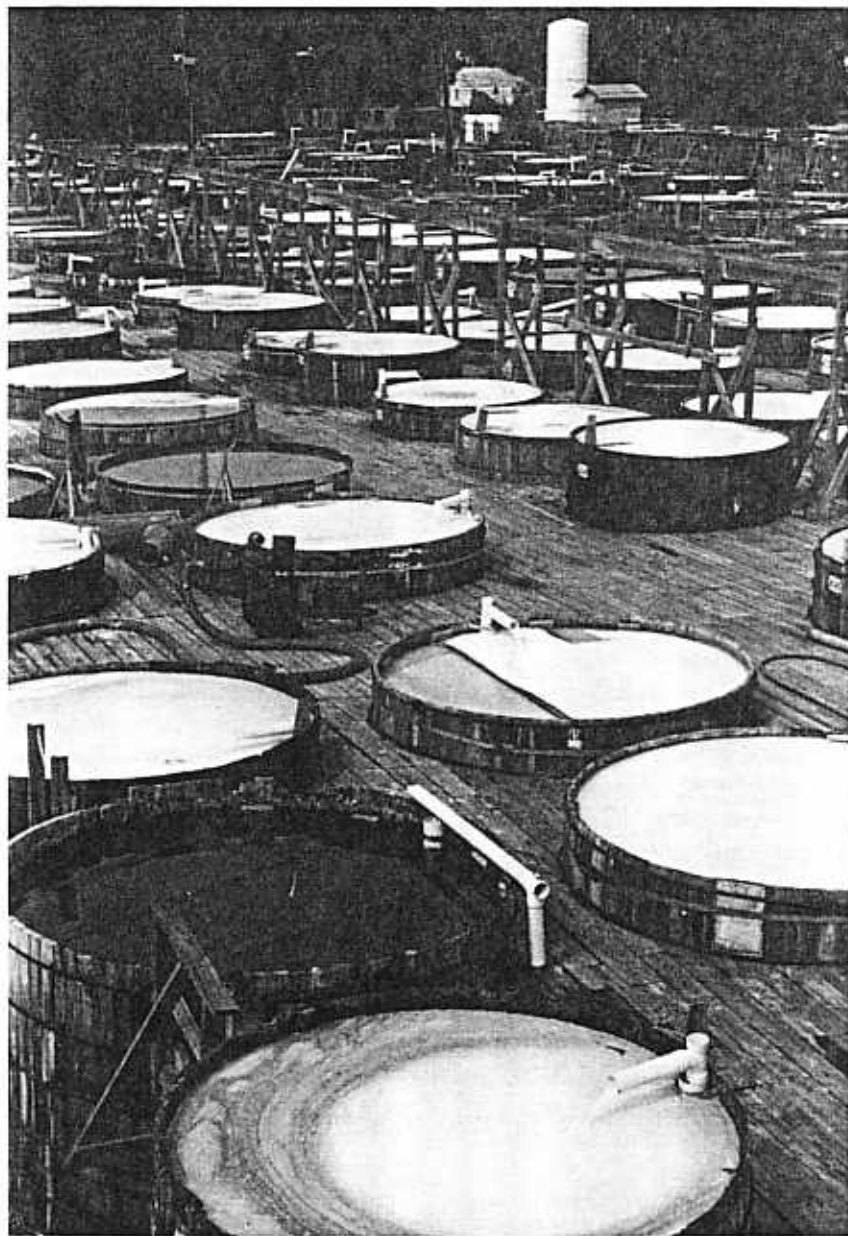


FIGURE 4. Brine tanks with cucumbers stored for later use. Purging with nitrogen gas can be seen in most tanks. Side-arm spargers carry nitrogen to the bottom of brine tanks. Nitrogen is dispensed from the tall white tank in the upper right portion of the picture.

for pickling cucumbers was  $10^{\circ}\text{C}$  and with relative humidity of about 95%. Those conditions minimized the undesirable effects of the agents studied.<sup>52</sup>

Low-temperature injury can occur when cucumbers are stored at critical temperatures (under  $7^{\circ}\text{C}$ ). Such injury is characterized by surface pitting, susceptibility to decay, collapse of tissue, and shriveling.<sup>53,54</sup>

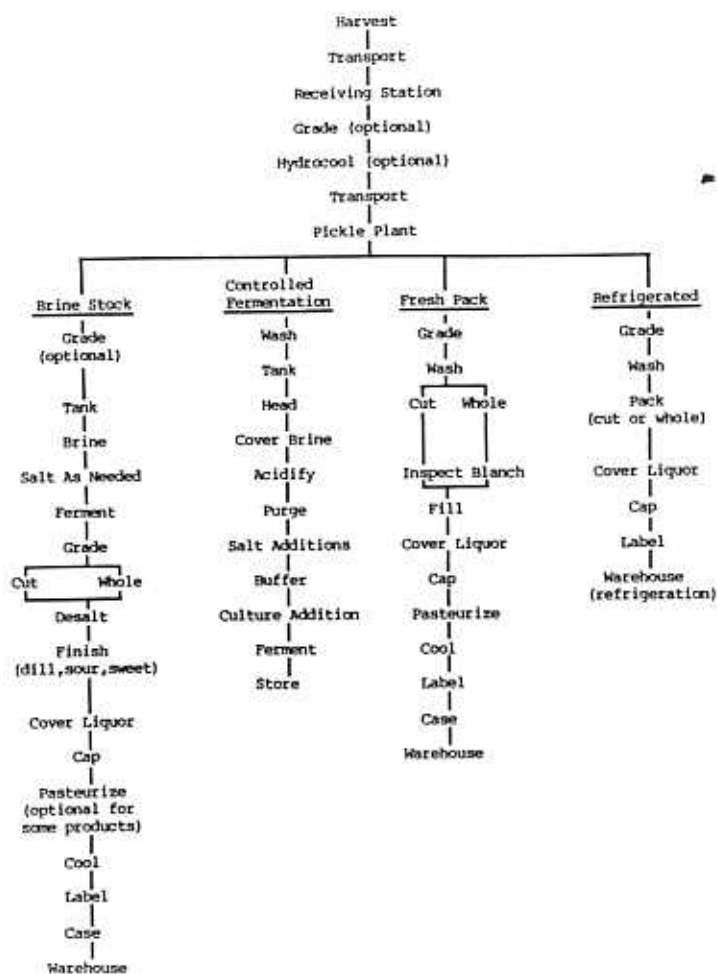


FIGURE 5. Flow chart depicting the movement of cucumbers from the field to finished pickles. Four procedures are given. (Adapted from References 58 and 65.)

### III. PROCESSING

#### A. Brining and Storage in Brine

Brining, which may or may not be accompanied by fermentation, has long been used for commercial bulk storage of many fruits and vegetables. It is a low-energy means for temporary storage of perishable produce (Figures 4 and 5). Cucumbers undergo a lactic acid fermentation during storage. Fermentation offers the advantages of acid formation and removal of fermentable sugars which serve to prevent growth of pathogenic microorganisms and to stabilize the products. Also, fermentation offers the potential for flavor enhancement in the products.<sup>55</sup>

Cucumbers are brined initially in solutions containing 5 to 8% sodium chloride during fermentation which translates to 19 to 30° salometer.<sup>56</sup> After fermentation, applications of dry salt might be sufficient for the cover brines to reach as high as 60° salometer for storage.<sup>57</sup> High concentration of salt is used to prevent softening spoilage during storage and to prevent freezing of brines in Canada and the northern U.S.

Before pasteurization, preservation of pickles relied upon the conversion of fermentable

carbohydrates to organic acids during bulk storage, and/or the addition of sufficient amounts of vinegar, sugar, and other ingredients to fully cured and packed cucumbers in order to minimize microbial growth. The preservation of genuine dill pickles which were not pasteurized, depended upon the added salt, the acid formed, and by being "fully cured". "Fully cured" refers to the complete removal of fermentable sugars and a change in the flesh from an opaque to a translucent appearance. Processed dill pickles and sour pickles were also prepared from fully cured brine stock, but final products were acidified further with acetic acid. Although such fully fermented, unpasteurized products were not subject to gaseous spoilage, the pickles were subject to softening during storage. Even today, however, some packers do not pasteurize genuine dills, while others do as added insurance against softening.<sup>55</sup>

When cucumbers are properly brined, fermentation proceeds in stages.<sup>58</sup> The initiation stage may include the growth of many of the microorganisms originally present on the fresh cucumbers. As lactic acid bacteria become established, the pH value of the brine drops and the growth of undesirable microorganisms such as Gram-negative and spore-forming bacteria is inhibited. During the primary fermentation stage, lactic-acid bacteria and fermenting yeasts are the most prevalent microorganisms in the brine tank. They grow in the brine until the fermentable carbohydrates are exhausted or until the lactic acid bacteria are inhibited by low pH values resulting from the production of lactic and acetic acids. Secondary fermentation is caused largely by fermentative yeasts which become established during primary fermentation. These yeasts are acid tolerant and continue to grow as long as fermentable carbohydrates are present. During the postfermentation stage, microbial growth is restricted to the surface of brines exposed to air.

The principal bacteria that function in cucumber fermentation are *Lactobacillus brevis*, *Pediococcus cerevisiae*, and *L. plantarum*.<sup>59</sup> Cucumbers and other vegetables fermented by *Lactobacillus plantarum* with pH control were microbiologically stable during 12 months of storage in hermetically sealed jars at 24°C provided all fermentable sugars were used up during fermentation and the products were stored at pH 3.8 or below.<sup>55</sup>

Major defects of cucumber fruits that can occur during brine storage include bloating, softening, bleaching, and the development of off-flavors and -odors. Bloating is most serious in large fruits (over 38 mm diameter) and has been attributed to the production of excess carbon dioxide in the cucumber tissue.<sup>60</sup> The firmness of brined cucumbers can be retained at lower brine strength than currently used provided the cucumbers are washed prior to brining (to remove flowers which harbor softening enzymes), and the temperature of the brine stock is maintained at 15.5°C or lower.<sup>61</sup> The addition of 0.1% calcium chloride to the brine resulted in firmer cucumbers, particularly those stored at pH 3.3 as opposed to pH 3.8.<sup>62</sup> More recent recommendations call for 0.2 to 0.35% calcium chloride at equilibrium.<sup>63</sup> Purging of carbon dioxide from brine tanks by bubbling nitrogen gas into them (Figure 4) has become a widely accepted practice.<sup>64,65,66</sup> Air purging is also used,<sup>66</sup> but can result in softening of cucumbers due to fungal growth,<sup>67</sup> and other quality problems.<sup>68</sup> Softening of fruit has been related to fungi carried on the surface of the fruits and in the flowers that often remain attached to small fruits.<sup>61</sup> In addition to washing the fruits as mentioned earlier, softening can be reduced greatly by draining and refilling tanks after the first 36 h of storage.<sup>69</sup> Bleaching is caused by exposure of brine stock to sunlight. Off-flavors and odors result from the growth of undesirable microorganisms. They can be controlled by maintaining favorable conditions, including good sanitation.

## B. Controlled Fermentation

Because there is much bloating of brine stock during uncontrolled fermentations, a procedure for controlled fermentation of cucumbers has been developed (Figure 5) and is described below.<sup>64,65</sup>

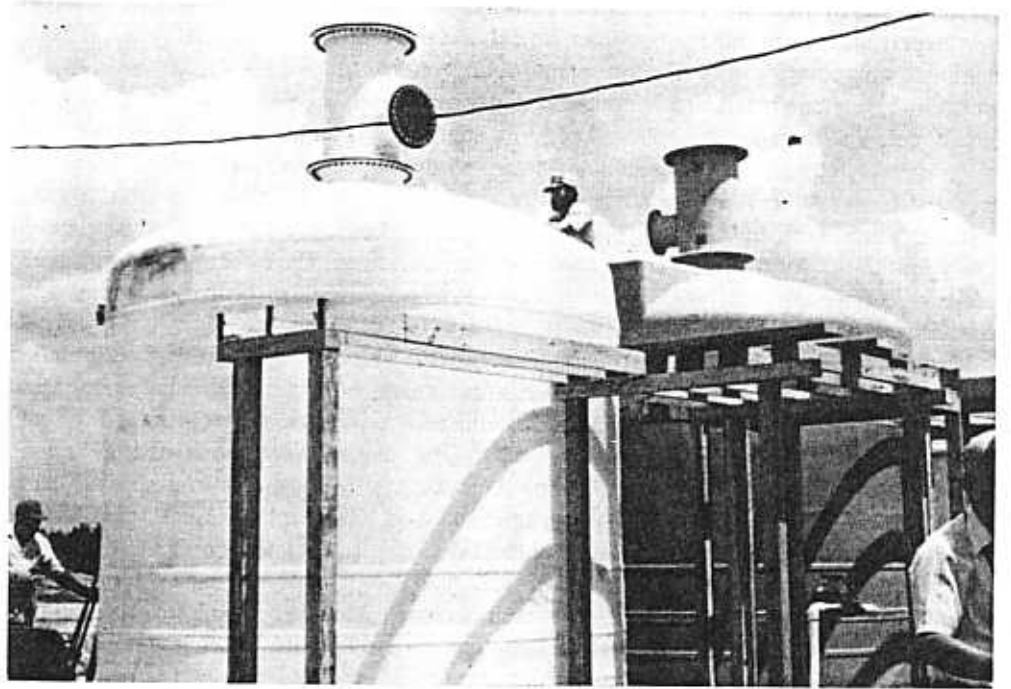


FIGURE 6. Closed-top tanks for use in controlled culture fermentation of cucumbers. See Reference 70 for a description of the cooperative research that is underway.

1. Select high quality green-stock and wash carefully using a brush- or reel-type washer.
2. Place cucumbers into a tank and add a 25° salometer brine to shrink the fruits.
3. Head the tank with boards and key-down timbers. Holes (10 mm diam.) should have been bored in the heading material to permit the escape of gases.
4. Add a chlorinated (about 80 ppm) 25° salometer brine. Brine level should be 0.1 m below the top of the tank and 0.2 m above the header boards.
5. Acidify the chlorinated cover brine carefully with glacial acetic acid or its equivalent of vinegar. For acetic acid, the proper amount is 1.6 ml/l of brine and cucumbers. A tank with 11,500 kg of cucumbers in it will require 27.6 l of acetic acid, or 10 times that much 100-grain vinegar.
6. Add enough salt to the head board of the tank to maintain the desired 25° salometer brine. About 6 kg of salt per 100 kg of cucumbers will be required.
7. The strength of the brine should be held at 25° ( $\pm$  2°) salometer for 7 to 12 days. Thereafter, the brine strength should be raised to the concentration used by the processing plant.
8. Purge with nitrogen gas at the rate of 425 dm<sup>3</sup>/h. The purging should begin 24 h after brining was started.
9. About 24 h later, neutralize the cover brine to pH 4.7 with sodium hydroxide.
10. Inoculate brine with 28 g of commercial culture of *Lactobacillus plantarum*, resulting in billions of cells per liter of brined material.
11. Fermentation: all cucumbers should ferment to completion in about 2 weeks. The brine temperature during fermentation should be about 27°C.

Attempts are being made to develop a closed-top tank for fermentation and storage of brined cucumbers.<sup>70</sup> Tanks are made of fiberglass or other synthetic materials (Figure 6)

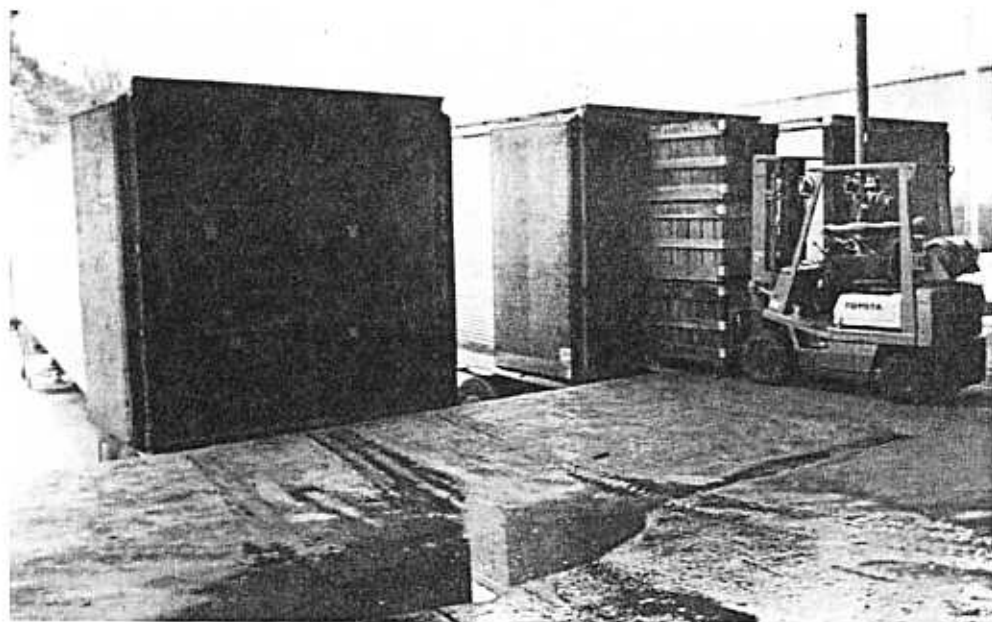


FIGURE 7. Cucumbers being loaded into refrigerator trucks. In this case, the cucumbers are in 705-1 (20 bushel) bins.

and, unlike wooden tanks, can be made virtually anaerobic. The research is cooperative among the U.S. Department of Agriculture, North Carolina State University, and the pickle industry.

Demethylation of pectin was the major change in cellular constituents which occurred during controlled fermentation of cucumbers.<sup>71</sup> Mesocarp firmness increased when pectin was demethylated, but the firmness subsequently decreased. Calcium chloride at 20 and 40 mM prevented loss of firmness compared to fresh cucumbers during 11 months of storage.

### C. Pickling and Finishing

#### 1. Refrigerated Dills

Other names that have been applied to this type of processing include "overnight dills" and "half-sours". The refrigerated dill is essentially a nonheated, well-acidified, low-salt content, refrigerated green cucumber, containing one or more preservatives with spices and flavoring.

Typically, overnight dills are made from the freshest cucumbers possible. Even when the cucumbers are harvested many hundred kilometers away from the processing plant, they are cooled immediately (Figure 3) and shipped (Figure 7) under refrigeration (7 to 10°C). At the pickle processing plant and still under refrigeration, the cucumbers are washed thoroughly (Figure 8) and packed by hand into containers. The cucumbers are then covered with a brine consisting of water, acetic acid (vinegar), and salt. The equilibration pH desired is 4.2 to 4.3 with a titratable acidity of 0.3 to 0.5% as acetic acid. Always dill, and usually garlic, along with other flavoring agents, plus sodium benzoate as a preservative are added. The containers are closed, cased, and moved to a refrigerated warehouse.<sup>58,72</sup> Overnight dills are kept refrigerated in marketing channels until purchased by the consumer. Refer to Figure 5 for a flow diagram.

#### 2. Pickles From Fresh Cucumbers

Several kinds of pickles are made from fresh cucumbers, including whole dills, hamburger

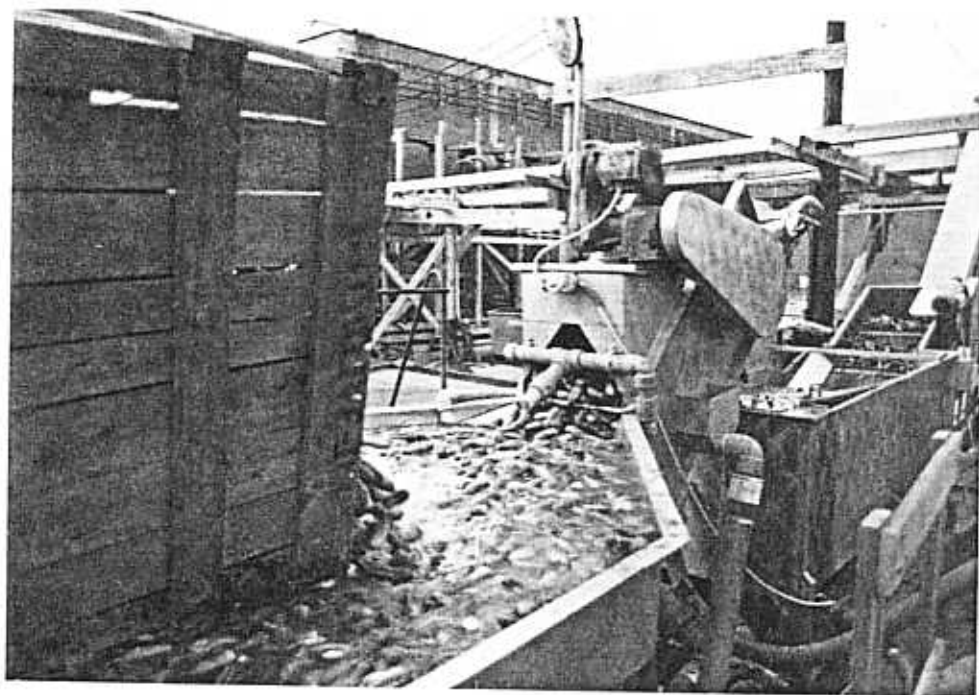


FIGURE 8. Cucumbers being dumped into a washer before being conveyed into the processing plant.

slices (crosscut), spears (cut lengthwise), bread and butter pickles, and others. Each company has its own blend of spices and flavorings which are added to the containers of cucumbers. Characteristically, spices are added to the bottom of the container before it is filled with cucumbers. Certain containers can be filled partially with either whole or crosscut cucumbers with machinery designed for that purpose. Spears, however, must be packed by hand (Figure 9). When the jars have been filled with cucumbers, a cover liquor consisting of water, vinegar, salt, and other flavoring agents is added. The jars are then capped and sent through the pasteurizer (Figure 10). In the steam operated pasteurizer, internal temperatures of the cucumbers are maintained at 74°C for 15 min.<sup>73</sup> The jars of cucumbers are then cooled, labeled, cased, and warehoused (Figure 5). The label usually states that the product is "fresh pack".

### 3. Pickles From Brined Cucumbers

#### a. Desalting and Preparation

After curing in salt brine, the original white interior of cucumbers will have changed to a uniform translucency and will contain 15% or more salt.<sup>57</sup> Desalting is accomplished by immersing the salt stock in several changes of fresh water, although a continuous flow of water will result in more rapid desalting of the brinestock. Heating the water also speeds the desalting process. Small grades and cut stock lose salt more rapidly than large grades. Equilibrium of salt between small stock and water will occur overnight. Equal parts water and stock result in halving of the salt in the stock. Two parts water and one part stock results in reduction of salt in the stock by two-thirds, etc. Because the final pickling syrup contains no salt, desalting should be halted when the salt level in the cucumber reaches 150 to 200% of that desired in the finished product. Once the proper degree of desalting has been accomplished the stock can be made into pickles (dill, sweet, sour, etc.).

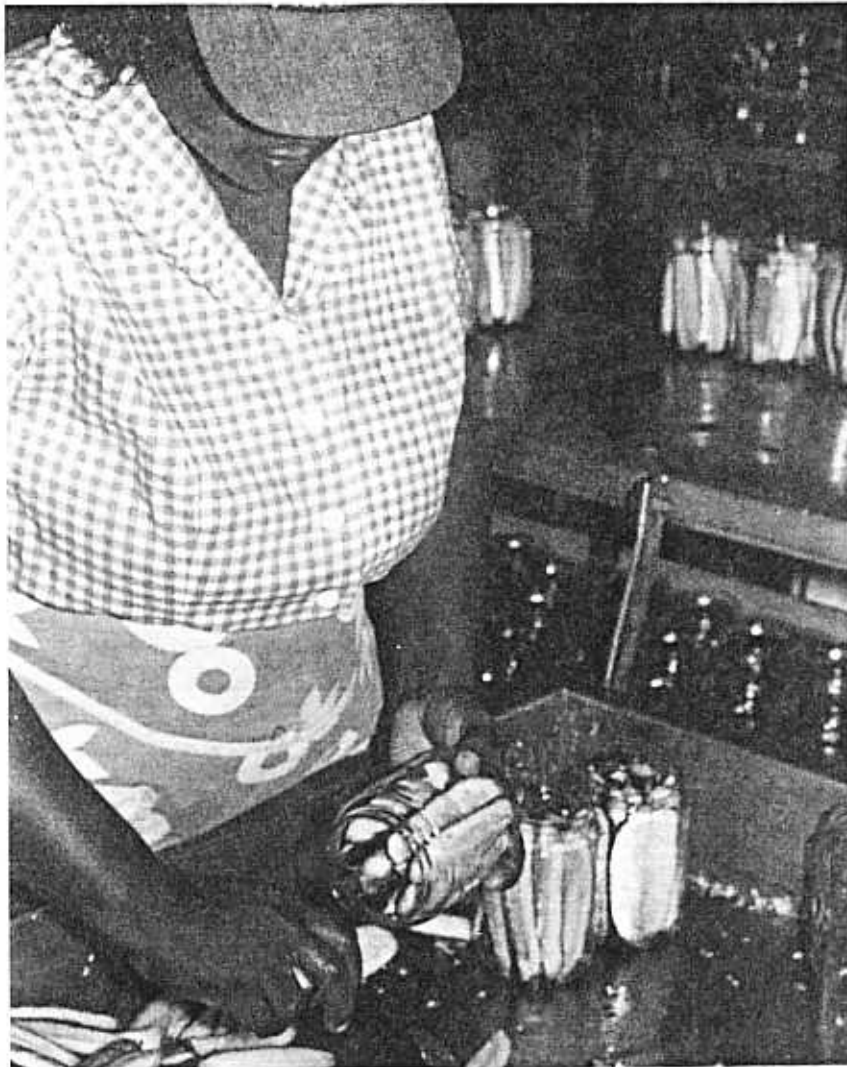


FIGURE 9. Cucumber spears being packed into jars by hand.

#### *b. Process Pickles*

Once the brined cucumbers have been sufficiently desalted, they are processed into genuine dills, sweet pickles, sour pickles, relishes, and other products.<sup>74</sup> After the desalted cucumbers have been placed in the jar, or other container, they are treated in a similar manner to that described for fresh pack pickles. Certain of these products might not be pasteurized, provided that sufficient vinegar, sugar, and preservatives have been added to assure long shelf-life.

### IV. SANITATION AND WASTE DISPOSAL

#### **A. Sanitation**

It is extremely important that processing plants be kept as clean as possible. Floors and other surfaces should be constructed of impervious materials that can be cleaned easily. Graders, washers, and inspection belts should be mounted high enough above the floor to facilitate the removal of dropped materials. Workers themselves should be instructed in

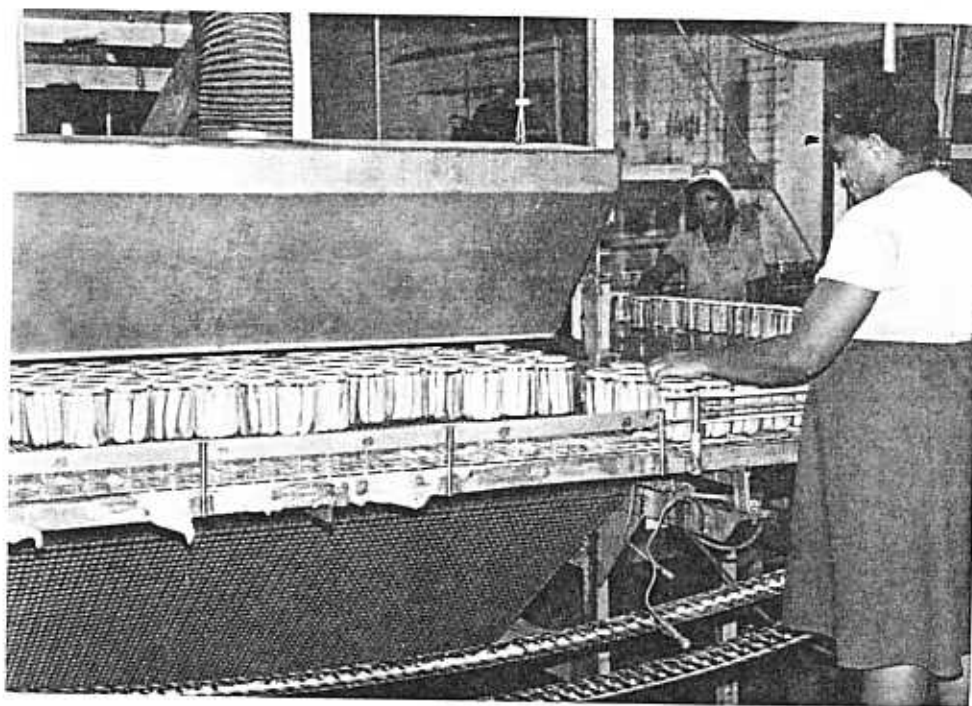


FIGURE 10. Cucumbers in jars being pasteurized.

keeping the work area clean. Properly sized and sloped gutters equipped with gratings where the floor is likely to get wet are also a must. Clean, freshly painted restrooms and cafeterias help encourage the employees to uphold standards of sanitation.<sup>75</sup>

Many sanitation problems within the processing plant can be eliminated by proper cleaning of the product before it enters the plant. Soil, leaves, stems, sticks, and field debris can be removed effectively by suitable cleaning machinery. Further, such machinery should be mounted on concrete slabs or other surfaces that will help keep them clean. Frequent removal of dropped cucumbers will do much to minimize troubles with flies, vinegar gnats, rodents, and other pests.

#### **B. Waste Disposal**

Broken cucumbers, stems, leaves, and other debris can be picked up and taken to a local dumping area. Liquid and solid waste from within the processing plant must be disposed of in a different manner. Processing plants within municipalities might utilize city sewage systems if they can handle the volume. Processing plants located in more rural areas must provide their own waste disposal systems. A popular and satisfactory system involves the use of lagoons. A typical lagoon system involves a highly aerated primary lagoon where waste from the processing plants are pumped (Figure 11). After action by bacteria, fungi, and other agents which break down the solid materials, the effluent is pumped into a secondary lagoon which has been equipped with baffles to provide a settling area. The effluent from the secondary lagoon is then pumped onto a bed of sand, where final action takes place.

In general, waste waters from cucumber operations are high in sodium chloride and have a high oxygen demand, along with a low pH, and high total and suspended solids content.<sup>76</sup>

Some of the most difficult wastes to dispose of are those from tank yard operations. The several sources of such wastes include spillage, tank overflow during rainy periods, leakage from wooden tanks, spent fermentation brine, and "process water" generated during de-





FIGURE 11. Waste treatment lagoon at a pickle-processing plant.

salting operations.<sup>77</sup> Usual fermentation practices will result in production of about 40% by volume of spent brine in a fermentation tank. Fermentation is normally accomplished with a brine containing 6.5% sodium chloride. However, once fermentation has been completed, processors usually add more salt, bringing the brine to 9 to 15% salt with a pH of 3.2 to 3.5.

Reuse of spent brines could result in significant reduction of waste disposal problems in addition to the savings generated by a reduced use of salt. Unfortunately, spent brines carry softening enzymes that would cause softening of cucumbers treated with it. Studies were conducted to determine the adequacy of certain brine treatments to neutralize softening agents. Heat treatment of 80°C for 30 s was sufficient to inactivate pectinases from molds common on fruits and flowers. Chemical treatment involved raising the pH of the brine to 11.0 or higher for 36 h which resulted in 99% inactivation of pectinases. Brine pH was raised by sodium hydroxide and lowered by hydrochloric or acetic acid.<sup>77</sup>

Close observation and evaluation of processes associated with a commercial pickle processing plant revealed that as much as 33% of the salt purchased might be wasted. Further, efficiencies in water usage could be installed to result in 40 to 90% savings.<sup>76</sup> Recommendations included the use of nonleaking tanks, strict supervision of dry salt and brine handling, the installation of water meters to monitor water usage in the several areas of the processing plant, treatment and reuse of spent brines, removal of suspended solids from waste waters, the capture of pasteurizer water for use in cleanup, and the adoption of lower salometer storage for saltstock.

It should be emphasized that pure culture fermentation techniques result in the use of less salt and generally higher yields of product than natural fermentation procedures.<sup>78</sup>

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