containers may be constructed of burlap, paper, fiberboard, wood, or plastic. Because of the mass of materials at receiving points, there is increasing emphasis on materials that are recyclable or reusable.

PROJECTIONS FOR THE FUTURE

What are the expectations for the commercial vegetable industry as we enter the twenty-first century? Some thoughts on this question follow: Vegetables will continue to be consumed in greater quantities; there will be an ever-increasing variety of vegetables from which consumers can choose; organically grown vegetables will command a greater proportion of the market; the vegetable industry will be global rather than national as trade barriers are loosened; there will be fewer new pesticides available to growers and increased monitoring of pesticide usage; the use of genetically enhanced vegetable varieties will become commonplace; and the number of vegetable enterprises will decrease, but those remaining will be larger.

BIBLIOGRAPHY

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1. The Staff of The Liberty Hyde Bailey Hortorum, *Hortus Third*, MacMillan Publishing Co., New York, 1976.
2. D. N. Maynard, "Vegetable," in S. J. Foderaro, ed., *Academic American Encyclopedia*, Vol. 19, Aretê Publishing Co., Princeton, N.J., 1980, pp. 531–534.
3. S. J. Kays and J. C. Silva Dias, *Cultivated Vegetables of the World*, Exon Press, Athens, Ga., 1996.
4. H. Chen et al., "Diversity of Edible Vegetables in China," in V. E. Rubatzky, H. Chen, and J. Y. Peron, eds., *Proc. Third Int. Symp. on Diversification of Vegetable Crops*, Acta Horticulturae No. 467, International Society for Horticultural Science, Leuven, Belgium, 1998.
5. Anonymous, *Vegetables. 1997 Summary*, Vg 1-2(98), U.S. Department of Agriculture Washington, D.C., 1998.
6. Anonymous, *FAO Production Yearbook 1996*, FAO Statistics Series No. 135, Food and Agriculture Organization of the United Nations, Rome, 1997.
7. D. Chen and M. Liu, "An Overlook at Vegetable Production, Consumption, Distribution and its Progress in China," in V. E. Rubatzky, H. Chen, and J. Y. Peron, eds. *Proc. Third Int. Symp. Diversification of Vegetable Crops*, Acta Horticulturae No. 467, International Society for Horticultural Science, Leuven, Belgium, 1998.
8. G. Lucier, *Vegetables and Specialties. Situation and Outlook*, VGS-275, U.S. Department of Agriculture, Washington, D.C., 1998.
9. I. L. Nonnecke, *Vegetable Production*, Van Nostrand Reinhold, New York, 1989.
10. D. N. Maynard and G. J. Hochmuth, *Knott's Handbook for Vegetable Growers*, 4th ed., John Wiley & Sons, 1997.
11. H. Krug, "Environmental Influences on Development, Growth and Yield," in H. C. Wein, ed., *The Physiology of Vegetable Crops*, CAB International, New York, 1997.
12. J. F. Thompson, "Harvesting Systems," in A. A. Kader, ed., *Postharvest Technology of Horticultural Crops*, 2nd ed. University of California, Oakland, Calif., 1992.

GENERAL REFERENCES

J. L. Brewster, *Onions and Other Vegetable Alliums*, CAB International, New York, 1994.
A. A. Kader, ed., *Postharvest Technology of Horticultural Crops*, University of California, Oakland, Calif., 1992.
D. N. Maynard and G. J. Hochmuth, *Knott's Handbook for Vegetable Growers*, 4th ed., John Wiley & Sons, New York, 1997.
R. W. Robinson and D. S. Decker-Walters, *Cucurbits*, CAB International, New York, 1997.
V. E. Rubatzky and M. Yamaguchi, *World Vegetables. Principles. Production, and Nutritive Value*, 2nd ed., Chapman and Hall, New York, 1997.
E. J. Ryder, *Lettuce, Endive. and Chicory*, CAB International, New York, 1999.
H. C. Wein, ed., *The Physiology of Vegetable Crops*, CAB International, New York, 1997.
R. Wills et al., *Postharvest. An Introduction to the Physiology & Handling of Fruit, Vegetables. & Ornamentals*, 4th ed., CAB International, New York, 1998.

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VEGETABLES, PICKLING

Vegetables may be preserved by fermentation, direct acidification, or a combination of these along with other processing conditions and additives to yield products that are referred to as pickles. Pasteurization and refrigeration are used to ensure stability of certain products. Organic acids and salt (NaCl) are primary preservatives for most types of pickles. Lactic acid is produced naturally in fermented products. Acetic acid (or vinegar) is the usual acid added to pasteurized, nonfermented (fresh-pack) pickles. Acetic acid also is added to many products made from fermented (salt-stock) cucumbers. Other preservatives such as sodium benzoate, potassium sorbate, and sulfur dioxide may be added to finished products. Although the term *pickles* in the United States generally refers to pickled cucumbers, the term is used herein in a broader sense to refer to all vegetables that are preserved by fermentation or direct acidification. Cucumbers, cabbage, olives, and peppers account for the largest volume of vegetables and fruits commercially pickled. Lesser quantities of onions, tomatoes, cauliflower, carrots, melon rinds, okra, artichokes, beans, and other produce also are pickled.

Although this article emphasizes pickling of cucumbers and cabbage, which are major vegetable commodities commercially preserved and consumed in the United States and Europe, and kimchi, which is a mixture of fermented vegetables consumed in Korea, most vegetables have been preserved by pickling, either commercially or in the home.

HISTORY

The preservation of vegetables by fermentation is thought to have originated before recorded history, and the technology was developed by trial and error. Pederson (1) presumed that early humans observed that when vegetables were flavored with salt or brine and packed tightly in a vessel, they changed in character but remained appetizing and nutritious. Pederson concluded that the Chinese were the first to preserve vegetables in this manner and assumed that fermentation in salt brines occurred first and that dry salting came later. The Chinese have been credited with introducing fermented vegetables into Europe.

Pasteurization, as a means of preserving acidified vegetables, was introduced in the United States in the 1940s. Before then, all pickled vegetables were preserved commercially by fermentation. Pasteurization resulted in a doubling of the per capita consumption of pickled vegetables by the 1950s. Refrigerated pickles were introduced into U.S. commerce in the 1960s and have been an increasing segment of the industry since.

PROCESSING

Processing methods for the preservation of cucumbers, cabbage, and kimchi will serve to illustrate the principles involved in vegetable pickling.

Cucumbers

Various authors have attributed the origin of the cucumber (*Cucumis sativus* L.) to Africa, China, India, or the Near East (2). Later domestication occurred throughout Europe, and cucumbers are now grown throughout the world using field or greenhouse culture, but with various characteristics, depending upon region.

Cucumbers are bred either for fresh market or processing (pickling). The fresh market varieties possess a relatively tough skin, which serves to extend their storage life as fresh produce. Pickling varieties, however, possess a thin, relatively tender skin. Pickling cucumbers are harvested in a relatively immature stage, before the seeds mature and before the seed area becomes soft and starts to liquify.

Cucumbers are harvested by hand or mechanical means, depending upon availability of labor, land size and conformation, and other factors. Cucumbers are a seasonal crop grown in various geographical regions and shipped to the processor. Great changes have occurred in the United States during the past 20 years as to the origin of the fruit that a processor receives. Although once a mainly regional and seasonal enterprise, some large processors now receive fresh cucumbers nearly the entire year. The fruit is grown from Mexico to Canada and shipped fresh to processors according to their demands. Cucumbers grown near the processor may be processed within 24 hours. Cucumbers are shipped under refrigeration if grown at distant locations from the processor. The demand for a year-round supply of fresh cucumbers varies according to the types of products that the processors manufacture. Brined cucumbers, being more stable, are transported intercontinentally.

Pickling cucumbers are preserved by three basic methods: fermentation (40% of overall production), pasteurization (40%), and refrigeration (20%), as outlined in Figure 1 (3). After pasteurization of fresh cucumber pickles was introduced into the U.S. industry in the 1940s, the consumption of pickles increased significantly because of the milder acid flavor and more uniform quality of the pasteurized product. The process involves heating properly acidified cucumbers to an internal temperature of 74°C and holding for 15 min (4). Some processors deviate from this standard process, depending upon their products and experiences. Fermented cucumbers also may be pasteurized to increase shelf stability, but at lower temperatures and times. Refrigerated pickles are preserved by addition of low concentrations of vinegar and a chemical preservative (eg, sodium benzoate), in addition to refrigeration at 1 to 5°C. Microbial growth in these products is not desired. Nonacidified, refrigerated pickles, originally popular among certain ethnic groups, also are marketed in some metropolitan areas. These products may or may not be allowed to undergo fermentation before refrigeration. After packaging, these nonacidified pickles undergo a slow lactic acid fermentation while under refrigeration.

Cabbage

The modern, hard-head cultivars of cabbage (*Brassica oleracea*) are reported to have descended from wild, nonheading *Brassias* originating in the eastern Mediterranean and in Asia Minor (5). Cabbage is grown for the fresh market and for the production of sauerkraut. For use in the production of sauerkraut, it is desired that the cabbage heads be large (typically 8–12 lb) and compact (ie, dense), have a minimum of green outer leaves, and possess desirable flavor, color, and textural properties when converted into sauerkraut.

Fresh cabbage for sauerkraut is harvested mechanically or by hand mostly from August to November. The cabbage is transported to the processor, where it is graded, cored, trimmed, shredded, and salted. The waste from the coring and trimming operations typically is returned to the field, where it is plowed into the soil. This waste constitutes about 30% of the weight of the fresh cabbage.

After shredding (about 1-mm thick), the cabbage is conveyed by belt, where salt is added, to the fermentation tanks. The tanks typically hold 20 to 180 tons of shredded cabbage. Most tanks today are constructed of reinforced concrete, but some wooden tanks remain. The tank is uniformly filled, heaped to extend slightly above the top of the tank, and loosely covered with plastic sheeting. After about 24 h, brine generated and located at the bottom of the tank is allowed to drain from the tank to allow the top of the cabbage to settle below the top of the tank. Then, the cabbage is manually distributed to create a slightly concave surface. Plastic sheeting then is placed on the surface, and water is added on top to weight it down and to provide an anaerobic seal. Gas generated during fermentation escapes by forcing its way between the tank wall and the cabbage, or through a plastic tube placed between the cabbage and the cover.

In the United States, the cabbage is allowed to remain in the tanks until at least 1% lactic acid is formed (about 30 days minimum, depending upon the temperature), and is stored beyond this time and until such time as needed

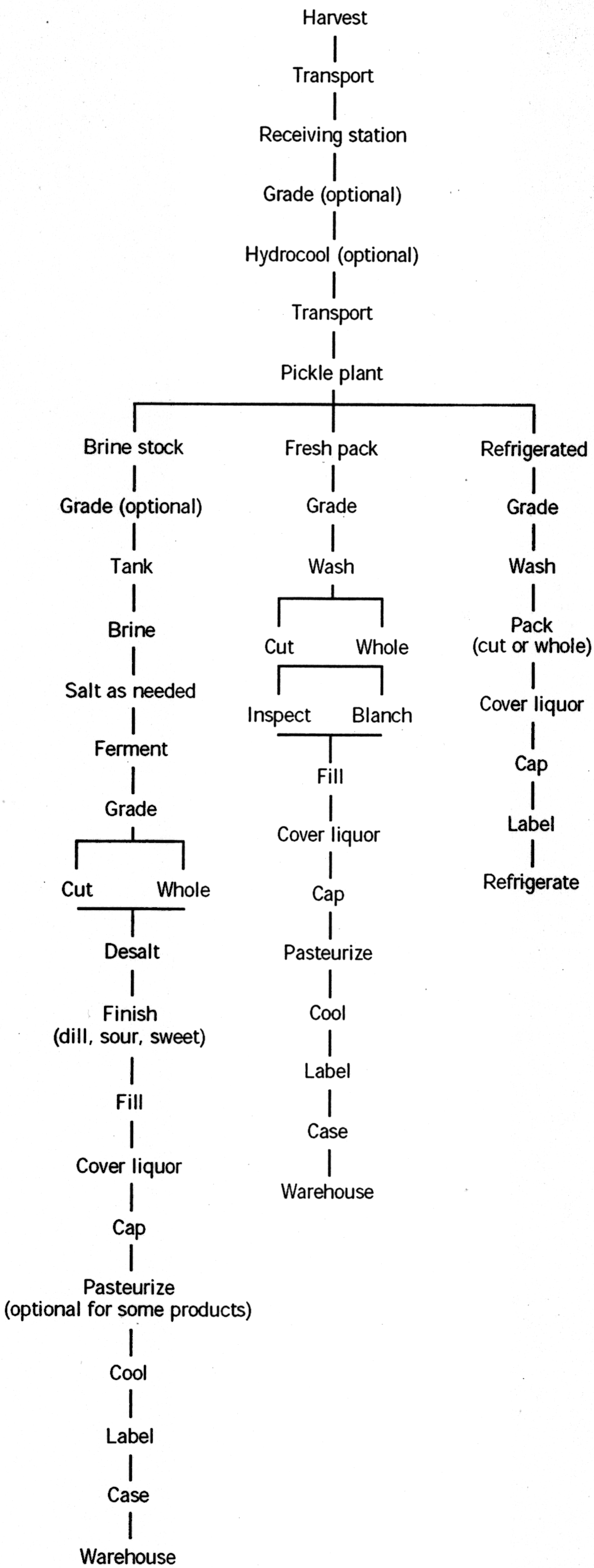

Figure 1. Flow diagrams for three methods of cucumber processing. *Source:* Ref. 3.

for processing. Thus, the sauerkraut tanks are used for fermentation as well as storage. Although extended periods of holding in the tanks can result in excess acid formation and waste generation due to the need to wash excess acid from the product before canning, this disadvantage is offset by the economic advantages of bulk storage. Also, most U.S. sauerkraut companies specialize in this product only and desire the option of further processing of sauerkraut throughout the year so as to distribute labor and equipment needs. This U.S. procedure differs significantly from that of many European manufacturers who process the sauerkraut into finished products when it reaches the desired level of titratable acidity (calculated as lactic acid, typically 1%). Thus, European manufacturers have greater control over product uniformity, but lose the economic advantages of bulk storage. Also, the European method results in less waste generation since less excess acid is produced.

The sauerkraut is removed pneumatically, by mechanical fork, or by hand from the tanks as needed for processing during the year. The sauerkraut may be packaged in cans, glass, or plastic containers. When packaged in glass or plastic, the product is not heated. Rather, sodium benzoate (0.1%, w/w) and potassium metabisulfite are added as preservatives, and the product is held under refrigeration (5°C).

Canned sauerkraut is preserved by pasteurization without the addition of preservatives. Heating is performed either by steam injection into a thermal screw or by a sauerkraut juice immersion-type cooker. The product is heated to 74 to 82°C for about 3 min and hot-filled into the cans. After closure, the cans are immediately cooled to less than 32°C.

Kimchi

Kimchi is a general term applied to a Korean product made by the lactic acid fermentation of salted vegetables (dry salted or brined) with or without secondary ingredients. Unless otherwise specified, however, kimchi generally means a product made from Chinese cabbage as the primary vegetable with secondary ingredients. Kimchis made from vegetables other than Chinese cabbage as the primary vegetable are specified with a qualifying word, eg, radish kimchi, cucumber kimchi, and green onion kimchi. Both solids and liquids of kimchis are consumed.

Kimchi has been a major table condiment in Korea for about 200 years. Kimchi provided a spicy and flavorful adjunct to a rather narrow choice of foods for Koreans in difficult times, complementing the bland taste of cooked rice.

Winter kimchi has been most traditional and is made between mid-November and early December, depending on the climate of the particular year. It is consumed until the following spring. The fresh ingredients are tightly filled into large earthen jars with earthen lids. The jars are partially buried (80–90% of container depth) under ground and are covered with bundles of rice straw for protection from direct sunlight and the climate. This procedure is still practiced in much of the rural areas and some households in urban areas. The subsurface temperature of the earth during the winter season is fit for slow but excellent fermentation of kimchi and also for the subsequent storage. Overacidification and development of yeasty flavor are the two most important problems in the long-term storage of kimchi. However, as the temperature goes up late in the following spring, the quality of winter kimchi is reduced.

Today, lesser amounts of winter kimchi are made, and Koreans now enjoy freshly fermented kimchi anytime of the year owing to year-round availability of fresh vegetables, general availability of household refrigerators, and distribution of commercial products through efficient cold distribution systems. Also, it is common for Korean families to make small batches of kimchi as needed and to store it under refrigeration for short periods to extend the fresh quality.

Kimchis can be divided into two types simply depending on the way the primary vegetable is salted. Primary vegetables are salted (either by dry salting or brining) and then the liquid is drained off completely before blending with secondary ingredients in the preparation of general kimchis. However, sufficient brine is poured over the packed ingredients to cover whole cucumber fruits or radish roots. Pickles are usually prepared without secondary ingredients.

FERMENTATION AND MICROBIOLOGY

Most vegetable fermentations are the result of growth by naturally occurring lactic acid bacteria present on the raw vegetable and the concentration of salt present, which dictates the types and extent of growth by these bacteria. The concentration of salt used varies among commodities (Table 1) and depends upon the flavor and textural properties desired. Cucumbers tend to soften (enzymatically) more if brined below about 5% NaCl. Fermentation of vegetables occurs in various stages (Table 2). The principal species of lactic acid bacteria and their metabolic end products are summarized in Table 3.

Glucose and fructose are the principle sugars of cucumbers and cabbage. Cabbage also contains low levels of sucrose. The metabolic pathways involved in fermentation of these sugars to end products are illustrated in Figure 2.

Leuconostoc mesenteroides is an important species for initiating the fermentation of sauerkraut and kimchi because of its production of acetic as well as lactic acid and nonacidic end products (ethanol, mannitol), which results in a more flavorful product. However, this species is rather acid sensitive and soon is overtaken by *Lactobacillus plan-*

Table 1. Brining Procedures for Vegetables

	Concentration (%, w/v) of salt		
Method of salting	Fermentation	Storage	Vegetable
Dry salting	1.5–2.5	1.5–2.5	Cabbage
Dry salting	3	3	Kimchi
Brine solution	5–8	8–16	Cucumbers

Note: The concentrations of salt indicated generally are used for the vegetables listed. Wide variations exist in the salt concentration used for peppers, onions, and cauliflower.

Table 2. Stages of Microbial Activities During the Natural Fermentation of Vegetables

Stage	Prevalent microorganisms (conditions)
Initiation of fermentation	Various Gram-positive and Gram-negative bacteria
Primary fermentation	Lactic acid bacteria, yeasts (sufficient acid has been produced to inhibit most bacteria)
Secondary fermentation	Fermentative yeasts (when residual sugars remain and lactic acid bacteria have been inhibited by low pH)
	Spoilage bacteria (degradation of lactic acid when pH is too high and/or salt/acid concentration is too low, eg, propionic acid bacteria, clostridia)
Postfermentation	Open tanks: surface growth of oxidative yeasts, molds, and bacteria
	Anaerobic tanks: none (provided the pH is sufficiently low and salt or acid concentrations are sufficiently high)

Source: Ref. 6.

Table 3. Lactic Acid-Producing Bacteria Involved in Vegetable Fermentations

Genus and species	Fermentation type[a]	Main product (molar ratio)	Configuration of lactate
Streptococcus faecalis	Homofermentative	Lactate	L(+)
Streptococcus lactis	Homofermentative	Lactate	L(+)
Leuconostoc mesenteroides	Heterofermentative	Lactate/acetate/CO_2 (1:1:1)	D(−)
Pediococcus pentosaceus	Homofermentative	lactate	DL, L(+)
Lactobacillus brevis	Heterofermentative	Lactate/acetate/CO_2 (1:1:1)	DL
Lactobacillus plantarum	Homofermentative	Lactate	D(−), L(+), DL
	Heterofermentative[b]	Lactate/acetate (1:1)	D(−), L(+), DL
Lactobacillus bavaricus	Homofermentative	Lactate	L(+)

Source: Ref. 7.
[a]With respect to hexose fermentation.
[b]Heterofermentative with respect to pentoses (facultatively heterofermentative).

tarum, which produces mainly lactic acid and can result in a harsh, too-acidic product. However, *L. mesenteroides* (a heterofermentor) produces CO_2 (a gas) that can cause bloater damage (gas pockets) in fermented cucumbers. For this reason, *L. plantarum* or *Pediococcus pentosaceus* (homofermentor of hexoses, ie, produces only lactic acid and no CO_2) is preferred for cucumber fermentations. Fortuitously, the texture of cabbage is retained at relatively low NaCl concentrations (1.5–2.5%), which is conducive to growth by *L. mesenteroides*. The higher salt concentration required for texture retention of fermented cucumber (5–8%) prevents growth by *L. mesenteroides*, but not *L. plantarum*, which is a preferred species to dominate cucumber fermentation because of its acid tolerance and homofermentative metabolism.

NUTRITIVE VALUE

The chief nutritive value of vegetables is in their content of vitamins, which may include important amounts of β-carotene, ascorbic acid, and folic acid, and less important amounts of riboflavin and some of the other B vitamins. Vitamin B_{12} is not present in vegetables. Vegetables used for fermentation are an important source of fiber, but contain low levels of protein and calories.

The effect of brining and fermentation on the nutritive value of vegetables has been reviewed (8–10); however, relatively little information is available on the subject. Lactic acid bacteria conventionally important in vegetable fermentations are nutritionally fastidious and would not be expected to increase essential nutrients during fermentation.

Although microbial action may alter the nutrient content of vegetables during fermentation, other factors may significantly influence the retention of nutrients during storage and further processing. If the vegetables are brined at high levels of salt, large losses in nutrients will result when the vegetables are subsequently desalted before use. From a nutritive standpoint, therefore, it would be preferable to brine vegetables at a low level of salt. Unfortunately, softening and other spoilage problems dictate the use of higher levels of salt in some vegetables than would otherwise be desirable. There is nearly complete loss of ascorbic acid from salt-stock cucumbers, which are stored at 8 to 16% salt, when the cucumbers are desalted to 2 to 4% salt for use in finished products. Fellers (9) reported 86, 82, and 28% losses for vitamin C (ascorbic acid), thiamin, and carotene, respectively, in desalted salt-stock cucumbers; but, in genuine dills, which are not desalted, 33 to 60% vitamin C retention was found. Sauerkraut requires only 2 to 3% salt for preservation and, therefore, is not desalted before use. Thus, vitamin C is largely retained during storage of sauerkraut, but may be diminished during later processing, depending upon exposure to air and the extent of heating.

Ascorbic acid and thiamin are stabilized by acid and exclusion of oxygen. Because fermented vegetables are normally held under such conditions, good retention of these vitamins would be expected. Current nutritional labels on commercial sauerkraut show a usual ascorbic acid content of 50% of the U.S. RDA per 100 g serving.

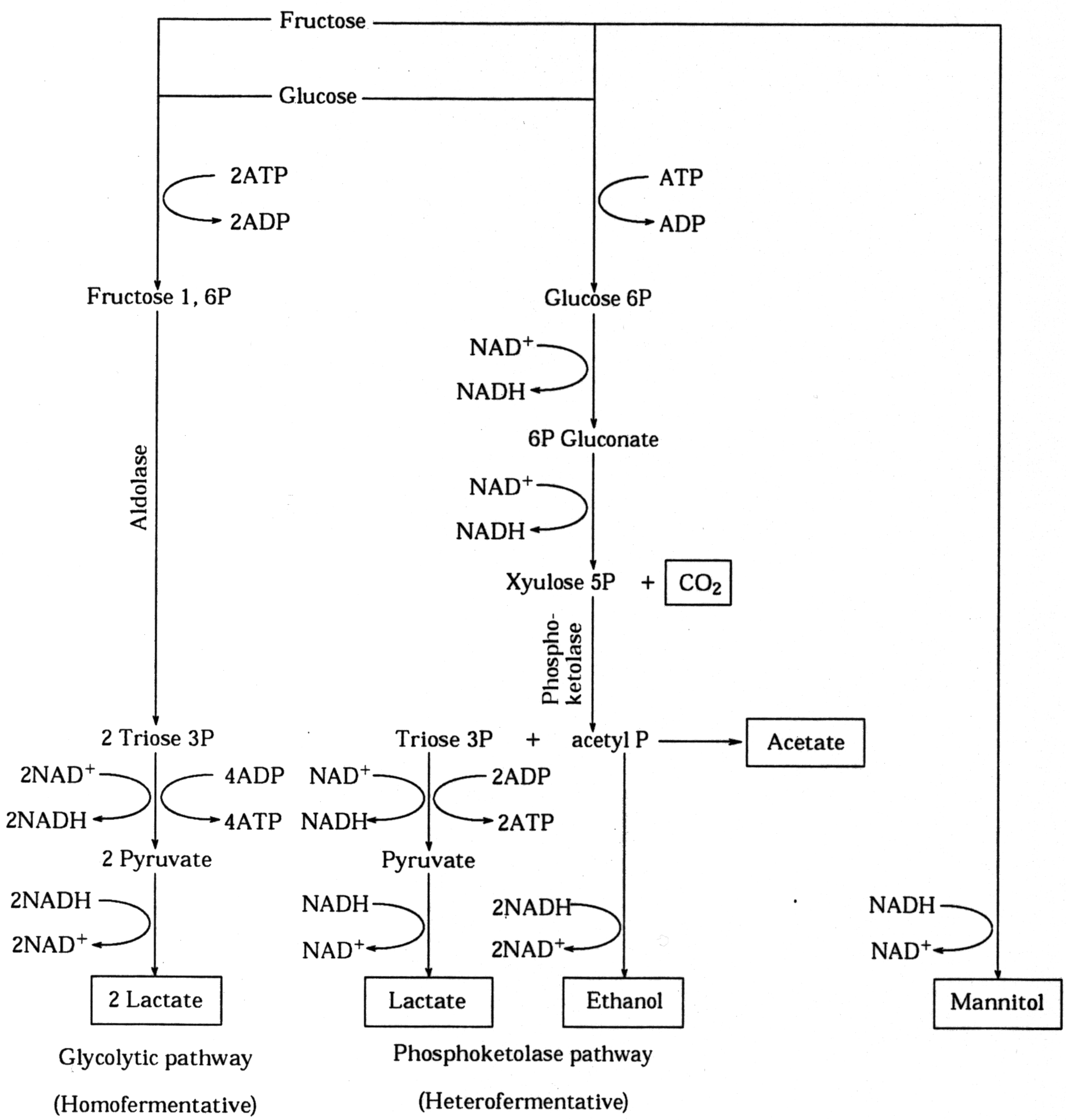

Figure 2. Major pathways for sugar fermentation by lactic acid bacteria. *Source:* Ref. 12.

SHELF LIFE AND BULK STORAGE

The shelf life of pasteurized pickles typically is 12 to 18 months, depending on storage temperature (22°C or below preferred). The shelf life of refrigerated pickles varies from a few weeks (nonacidified type) to several months (acidified type, with preservatives). The shelf life of sauerkraut depends largely on the integrity of the can. With enamel-lined cans, the shelf life typically is 18 to 30 months. Sauerkraut packaged in glass or plastic bags usually contains preservatives such as potassium bisulfite (for maintaining a light color) and sodium benzoate or potassium sorbate (as microbial inhibitors), which results in a shelf life of 8 to 12 months.

Fermented cucumbers held at 8% NaCl or higher before being processed into finished products can be held for a year or longer. The storage life is extended at higher salt concentrations. Sauerkraut is held at relatively low salt concentration (1.5–2.5%) in bulk storage, and typically is held for up to a year (United States) or only for a month or so (Europe).

SAFETY

There are no authenticated reports of pathogenic microorganisms associated with standard commercial pickle products prepared under good manufacturing practices of acid, salt, and sugar content (and combinations thereof) from brined, salted, and pickled vegetable brine-stock, including cucumbers. The Commissioner of the FDA stated that "No instances of illness as the result of contamination of commercially processed fermented foods with *Clostridium botulinum* have been reported in the United States" (11). Essentially the same pattern of consumer safety applies to fresh-pack (pasteurized) pickle products. The pasteurization process calls for the packed product to be acidified at the outset with a sufficient amount of food-grade organic acid (eg, vinegar, acetic acid, or lactic acid) to result in an equilibrated brine product pH of 4.0 or below (preferably 3.8). Vinegar (acetic acid) is usually the acidulant of industry choice for cucumber pickle products. The basic pasteurization procedure, with acidified product heated to an internal temperature of 74°C and held for 15 min, has been used successfully by industry since about 1940. Insufficient acidification of pasteurized pickles can result in butyric-acid-type spoilage, possibly involving public health concerns.

STARTER CULTURES

Currently, most vegetable fermentations rely on the natural microflora, although use of starter cultures has been suggested by various authors. Various reasons have been proposed to explain the lack of commercial use of cultures, including economics, lack of sufficiently unique and valuable properties to justify their use, and the fact that vegetables will undergo a natural lactic fermentation under proper environmental conditions (12). However, recent research with cucumbers, sauerkraut, and olives indicate that use of special cultures for vegetable fermentations may find application in the near future. Examples of novel properties of lactic acid bacteria cultures that make them potentially useful in commercial vegetable fermentations:

- *Inability to degrade malic acid to lactic acid and CO_2.* A culture of *L. plantarum* was developed by mutation and selection for use in cucumber fermentation. Because this culture does not produce CO_2 from malic acid, the natural acid present in cucumbers, it is being evaluated for use to ferment whole cucumbers to avoid the need for purging to prevent bloater damage.
- *Inability to produce biogenic amines.* Biogenic amines such as histamine are formed by decarboxylation of amino acids. Selection of cultures lacking this ability has been considered.
- *Exclusive l(+)-lactic acid formation.* Health concerns have been raised about the production of D(-)-lactic acid (10). Starter cultures that produce only L(+)-lactic acid have been developed.
- *Bacteriocin production.* Cultures of lactic acid bacteria that produce nisin and other bacteriocins have been isolated and may prove useful in inhibiting the growth of undesired bacteria in vegetable fermentations.
- *Bacteriophage resistance.* Bacteriophage sensitivity of starter cultures for use in preparing fermented dairy products is a serious concern. Although bacteriophage problems are not currently apparent with fermented vegetables, the problem may become significant when the use of starter cultures becomes more prominent.

BIBLIOGRAPHY

1. C. S. Pederson, *Microbiology of Food Fermentations*, 2nd ed., AVI Westport, Conn., 1979.
2. C. H. Miller and T. C. Wehner, "Cucumbers," in N. A. M. Eskin, ed., *Quality and Preservation of Vegetables*, CRC Press, Boca Raton, Fla., 1989, pp. 245–264.
3. H. P. Fleming and W. R. Moore, "Pickling," in I. A. Wolff, ed., *CRC Handbook of Processing and Utilization in Agriculture*, Vol. II, CRC Press, Boca Raton, Fla., 1983, pp. 397–463.
4. R. J. Monroe et al., "Influence of Various Acidities and Pasteurizing Temperatures on the Keeping Quality of Fresh-Pack Dill Pickles," *Food Technol.* **23**, 71–77 (1969).
5. M. H. Dickson and D. H. Wallace, "Cabbage Breeding," in M. A. Bassett, ed., *Breeding Vegetable Crops*, AVI, Westport, Conn., 1986, pp. 395–432.
6. H. P. Fleming, K. H. Kyung, and F. Breidt, "Vegetable Fermentations," in H. J. Rehm and G. Reed, eds., *Biotechnology*, Vol. 9, VCH, New York, 1995, pp. 629–661.
7. O. Kandler, "Carbohydrate Metabolism in Lactic Acid Bacteria," *Antonie van Leeuwenhoek* **49**, 209–224 (1983).
8. I. D. Jones and J. L. Etchells, "Nutritive Value of Brined and Fermented Vegetables," *Am. J. Public Health* **34**, 711–718 (1944).
9. C. R. Fellers, *Effects of Fermentation on Food Nutrients*, in R. S. Harris and H. Von Loesecke, eds., AVI, Westport, Conn., 1960, p. 161.
10. R. F. McFeeters, "Effects of Fermentation on the Nutritional Properties of Food," in E. Karmas and R. S. Harris, eds., *Nutritional Evaluation of Food Processing*, 3rd ed., Van Nostrand, New York, 1988, pp. 423–446.
11. FDA, "Acidified Foods and Low-Acid Canned Foods in Hermetically Sealed Containers," *U.S. Food Drug Admin.*, Fed. Reg. **44**, 16204, 1979.
12. H. P. Fleming, R. F. McFeeters, and M. A. Daeschel, "The Lactobacilli, Pediococci, and Leuconostocs: Vegetable Products," in S. E. Gilliland, ed., *Bacterial Starter Cultures for Foods*, CRC Press, Boca Raton, Fla., 1985, pp. 97–118.

GENERAL REFERENCES

S. Davidson et al., *Human Nutrition and Dietetics*, Churchill Livingstone Inc., New York, 1979.

J. L. Etchells, T. A. Bell, and W. R. Moore, Jr., "Refrigerated Dill Pickles—Questions and Answers," *Pickle Pak Science* **5**, 1–20 (1976).

H. P. Fleming and R. F. McFeeters, "Use of Microbial Cultures: Vegetable Products," *Food Technol.* **35**, 84–88 (1981).

H. P. Fleming, R. F. McFeeters, and M. A. Daeschel, "Fermented and Acidified Vegetables," in C. Vanderzant and D. F. Splittstoesser, eds., *Compendium of Methods for the Microbiological Examination of Foods*, 3rd ed., American Public Health Association, Washington, D.C., 1992, pp. 929–952.

H. O. Lee and I. W. Yang, "Studies on the Packaging and Preservation of Kimchi," *J. Korean Agricultural Chemical Soc.* **13**, 207–210 (1975).

J. R. Stamer, "Lactic Acid Fermentation of Cabbage and Cucumbers," in H. J. Rehm and G. Reed, eds., *Biotechnology*, Vol. 5, Verlag Chemie, Weinheim, Germany, 1983, pp. 365–378.

J. R. Stamer and B. O. Stoyla, "Stability of Sauerkraut Packaged in Plastic Bags," *J. Food Protection* **41**, 525–529 (1978).

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