Effects of Fruit Size on Fresh Cucumber Composition and the Chemical and Physical Consequences of Fermentation

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ABSTRACT: The composition of pickling cucumbers varied with fruit size, which affected buffer capacity, sugar utilization, terminal pH, and texture of the fermented fruit. We found that as cucumber size increased (from less than 27 to 51 mm in dia), malic acid, pH, buffer capacity, and dry matter content decreased, and glucose and fructose contents increased. Fruit firmness and bloater damage were greater in large than in small, fermented, whole cucumbers. Blanching (75 °C, 30 s) had little effect on the fermentation and prevention of bloater formation in finished products, regardless of fruit sizes. It was demonstrated that cucumber juice can serve as a model system for studying the metabolic, but not the physical (texture, bloater damage), consequences of lactic acid bacteria chosen as starter cultures for cucumber fermentation.

Keywords: cucumber, fermentation, lactic acid bacteria, sugar, glucose, fructose

Introduction

THE COMPOSITION OF CUCUMBERS VARIES WITH FRUIT SIZE AND cultivar (Jones 1940; McFeeters and others 1982; McFeeters and Lovdal 1987). Compositional factors such as pH, buffer capacity, and initial sugar content of the fruit may affect the extent of sugar utilization and terminal pH in cucumber fermentation. Complete sugar utilization by a chosen starter culture in cucumber fermentation and appropriate terminal pH are important to ensure microbial stability and texture retention in the product (Fleming and others 1995a). Some investigators (Jones and others 1940; Veldhuis and others 1941) showed that addition of sugar to the fermenting brine increased the incidence of bloater formation. This suggested that high initial sugar content (usually in large size) could result in incomplete fermentation by lactic acid bacteria, leading to secondary fermentation by fermentative yeasts and consequent bloater formation in the product. Fleming and others (1989) reported that small cucumbers, which underwent a normal primary lactic acid fermentation and had terminal pH 3.7, were subsequently spoiled by undesirable bacteria during storage. It was later determined that a terminal pH of 3.5 or lower is required for microbial stability, depending upon salt concentration (Fleming and others 1996). Some work has been done to determine the composition of cucumbers from different fruit sizes (McCombs and others 1976; Pharr and others 1977; McCreight and others 1978; McFeeters and others 1982). However, the information was not complete and some data reported were contradictory. The natural buffer capacity of cucumbers and its effect on cucumber fermentation have not yet been investigated.

Besides compositional differences, cucumbers from different sizes may also differ in structural characteristics such as skin thickness and tissue texture (McCombs and others 1976; Anderson and others 1988). Several reports suggested that the structural features of cucumbers are related to bloating susceptibility (Jones and others 1941; Sneed and Bowers 1970; Fleming and others 1973). Bloater damage is a more serious problem in larger sizes of cucumbers. Visible bloater damage in large-size cucumbers has been reported to occur early in their fermentation (Fleming and others 1973). In addition, softening enzyme activity in cucumbers also varies according to fruit size, affecting the firmness of the product, and, therefore, product quality (Fleming and others 1978; Fleming 1982). Blanching prior to fermentation has been suggested by Etchells and others (1964) and applied in controlled fermentation to reduce the incidence of bloater formation and to increase firmness retention of the fermented products (McDonald and others 1993; Fleming and others 1978; 1995a; 1995b). However, little work has been done to evaluate the effectiveness of blanching cucumbers from different fruit sizes on reducing bloater incidence. Furthermore, the effect of fruit sizes on sugar utilization during cucumber fermentation has not been fully investigated, especially with a malolactic-deficient strain of *Lactobacillus plantarum*, which has been suggested as a starter culture for commercial cucumber fermentation because it does not utilize malic acid in cucumbers to produce CO_2.

In order to get consistent starting materials for studying cucumber fermentation, cucumber juice has been used as a model system by several investigators (Daeschel and others 1988; McDonald and others 1993; Passos and others 1993; 1994; 1997) because of perishability of fresh fruit. However, cucumber juice itself became cloudy during fermentation, which interfered with the measurement of cell growth by optical density. To avoid the interference, juice was usually heated to 80 °C to remove the substances which would precipitate during fermentation. It is unknown whether the precipitation during heating affects the pH and buffer capacity of the juice and how different, or similar, cucumber juice fermentation is from whole cucumber fermentation.

The objectives of this study were: (1) to determine malic acid, glucose, fructose, dry matter content, natural pH, and buffer capacity in cucumbers from 3 fruit sizes; (2) to investigate the effect of fruit size on sugar utilization and terminal pH in cucumber juice, and on whole cucumber fermentations, by a malolactic-deficient strain of *L. plantarum* in low-salt (NaCl) brine supplemented with calcium acetate; and (3) to evaluate the effect of blanch treatment on firmness retention and bloater prevention of fermented cucum-

bers from the 3 fruit sizes. This information is needed for developing controlled fermentation systems to achieve complete fermentation of different sizes of cucumbers and to ensure the microbial stability and consistent high quality of pickle products.

Materials and Methods

Cucumbers

Three fruit sizes of fresh pickling cucumbers from the same cultivar (Cross Country) were obtained from a local farmer (near Mt. Olive, N.C., U.S.A.). The fruit sizes were based on diameter (size 1 = less than 27 mm, size 2 = 27 to 38 mm, size 3 = 39 to 51 mm). The cucumbers were carefully sorted for uniformity of size and shape, and absence of mold growth and mechanical damage, and then washed in a reel washer.

For blanch treatment, the washed cucumbers were placed in a wire basket. The basket containing 2.3 kg of cucumbers was submerged in a 75 °C water bath (62 L) for 30 s. The basket was kept in constant motion to ensure uniform heating of the cucumbers (Fleming and others 1978).

Whole cucumbers (approximately 2.08 kg) were packed in sterile 3.785-L (4-qt) jars and then cover brine was added to the 3.785-L (4-qt) mark. Blanched cucumbers and brine were transferred aseptically to the jars. All jars had lids with a single rubber septum so that brine samples could be withdrawn with a syringe.

Cucumber slurry and juice

Cucumber slurry and juice were prepared by freezing the fresh cucumbers at –20 °C overnight and then partially thawing and blending to a homogeneous slurry (Daeschel and others 1988). Portions of the slurry were distributed into jars of convenient sizes and stored at –20 °C. The rest of the slurry was filtered through cheesecloth. The juice was collected and distributed into jars and then stored –20 °C. As needed, the slurry or juice was thawed. Heated juice was prepared by heating juice in a water bath to 80 °C and then rapidly cooled to room temperature in a cold water bath. Both heated and unheated juices were centrifuged at 10000 × g for 20 min. The supernatant was collected and used in the study.

pH and buffer capacity

A pH meter (Model 825 MP; Fisher Scientific Co., Pittsburgh, Pa., U.S.A.) was standardized against buffers at pH 4.01 and 7.0. The pH meter was checked frequently to be sure it was still properly standardized. To measure the natural pH and determine buffer capacity of juice (heated and unheated) from different sizes of cucumbers, 30 mL of each juice was used. The juice was titrated to a pH around 2.0 with 0.099N HCl so as to be able to observe the shape of the titration curve beyond the usual end pH point of fermented cucumbers. To determine the buffer capacity of slurry, 80 g of slurry was used. In addition, a Tissumizer (Tekmar Company, Cincinnati, Ohio, U.S.A.) was used to provide vigorous stirring. A water bath was used to remove the heat generated from the stirring to maintain a constant temperature of 24 °C. Since the pH equilibrium upon the addition of each increment of acid was very slow, especially the slurry, even with vigorous stirring, the titration with each sample took about 1 h. Titration curves for juice and slurry were determined. Buffer capacity was defined and calculated as milliequivalents of HCl required to reduce the natural pH of 100 g sample to pH 3.5.

Drying

Frozen slurry was thawed and homogenized with a Tissumizer. Samples (about 30 g) were weighed into 2-oz glass jars and then put in an air oven for drying. The drying consisted of 3 stages: overnight at 70 °C, 3 h at 90 °C, and 3 h at 104 to 105 °C. After drying, the samples were covered with lids and transferred into a desiccator to cool. Sample weights were measured on an electronic analytical balance (Sartorius Research R 160P; Sartorius Instruments, McGaw Park, Ill., U.S.A.). Drying was continued at 104 to 105 °C until constant weight was obtained.

Brine and fermentation media

The cover brine for fermentation was prepared by heating it to 75 °C, and then cooling overnight in a refrigerator. The brine contained 4.4% NaCl, 39 mM $Ca(OH)_2$, and 137 mM acetic acid. The pH of the cover brine was 4.69. The cucumber or juice/brine pack-out ratio was 55/45, w/w, in all cases. After equilibration with cucumbers or cucumber juice, the brine contained 2% NaCl, 17.5 mM $Ca(OH)_2$, and 65 mM acetic acid, and was in the range of pH 4.83 to 4.90. The diluted juice was sterilized by filtration through a 0.22-mm filter (Costar, Cambridge, Mass., U.S.A.).

Culture

A malolactic-deficient strain of *L. plantarum*, MOP3-M6, was obtained from the culture collection at U.S. Food Fermentation Laboratory (Raleigh, N.C., U.S.A.). This strain was originally obtained by N-methyl-N'-nitrosoguanidine mutagenesis of its parent strain, *L. plantarum* MOP3 (Daeschel and others 1984), which was isolated previously from a commercial cucumber fermentation (Fleming and others 1988). The mutant strain does not produce CO_2 from malic acid (a natural acid present in cucumbers) and is being evaluated as a starter culture for a commercial cucumber fermentation process. The culture was stored at –84 °C in MRS broth (Difco Laboratories, Detroit, Mich., U.S.A.) containing 16% glycerol. When needed, the frozen culture was streaked onto an MRS agar plate. After incubation at 30 °C for 2 d, one isolated colony was transferred into 5 mL MRS broth. After growth at 30 °C for 1 d, 1 mL of the culture was transferred into 100 mL MRS broth supplemented with 2% NaCl and incubated overnight at 30 °C. The culture was harvested at late log phase by centrifugation (Sorvall RC-5B; Du Pont Co., Wilmington, Del., U.S.A.) at 3000 × g for 10 min at 10 to 15 °C and then resuspended in 100 mL of sterile 0.85% NaCl.

Inoculation and fermentation

The inoculum culture (1%, by volume) was added to each growth medium to give an initial cell level approximating 10^6 colony-forming units per mL (CFU/mL). Both juice and brined cucumbers were incubated at ambient temperature (23 to 25 °C). All treatments were in triplicate.

Analyses

Cell growth in cucumber juice broth was followed during the course of the fermentation by measuring optical density at 630 nm (OD_{630}) and plating on MRS agar with an automated spiral plater (Model 3000; Spiral Biotech, Inc., Bethesda, Md., U.S.A.). After incubation at 30 °C for 2 d, colony-forming units per mL (CFU/mL) were determined with a colony counter (Protos Plus; Bioscience International, Rockville, Md., U.S.A.).

For cucumber juice fermentation, a sample (1 mL) was taken aseptically at 1 to 6 h during the first 3 d. Thereafter, the sampling frequency was gradually reduced until the 40th d when acid concentrations and pH remained unchanged. For whole cucumber fermentation, a sample (3 mL) was taken aseptically from each jar every wk during the first mo, and then every 3 mo until 1 yr of fermentation. These samples were stored at –20 °C for later chemical analysis.

The NaCl concentration in brine was determined by titration with standard $AgNO_3$ using dichlorofluorescein as an indicator

Table 1— Effect of fruit size on malic acid, glucose, fructose, and dry matter content of pickling cucumbers[a]

Fruit size	Diameter (cm)	Malic acid (%)[b]	Malic acid (%)[c]	Glucose (%)[b]	Fructose (%)[b]	Total sugar (%)[b]	Total sugar (%)[c]	Dry matter (%)[b]
1	< 2.7	0.28 ± 0.02	5.59 ± 0.21	0.80 ± 0.02	0.95 ± 0.03	1.75 ± 0.02	34.93 ± 0.23	5.01 ± 0.01
2	2.7-3.8	0.22 ± 0.01	5.07 ± 0.12	1.04 ± 0.02	1.14 ± 0.03	2.17 ± 0.02	50.00 ± 0.29	4.34 ± 0.01
3	3.9-5.1	0.21 ± 0.01	4.83 ± 0.14	1.16 ± 0.02	1.25 ± 0.05	2.40 ± 0.06	55.17 ± 0.81	4.35 ± 0.02

[a]Each value represents the mean ± standard deviation of 3 independent samples; Cross Country cultivar.
[b]Fresh (wet) weight basis
[c]Dry weight basis

(Fleming and others 1992). The pH was measured with a pH meter (Model 825 MP; Fisher Scientific Co.). Sugars, organic acids, and ethanol were determined by the HPLC method of McFeeters (1993) using a cation-exchange column (Aminex HPX-87H; Bio-Rad Laboratories, Richmond, Calif., U.S.A.) with a 0.8 mL/min flow rate of 3 mM heptafluorobutyric acid at 65 °C. A conductivity detector (Model CDM-2; Dionex Corp., Sunnyvale, Calif., U.S.A.) and a pulsed amperometric detector (Model PAD-2; Dionex) were connected in series for detection of organic acids and sugars, respectively. Isobutyric acid and *meso*-erythritol were used as the internal standards in acid and sugar analyses.

Firmness and bloater evaluation

Firmness of fermented cucumbers was evaluated after storage for 12 mo. Fermented cucumbers were cut longitudinally into halves for firmness measurement (skin up) with a USDA fruit pressure tester (FPT) with a 7.9-mm-diameter tip (Bell and others 1955; Bell and Etchells 1961) and the force expressed as Newtons (N). Testing of halves was done to avoid using severely bloated fruit, which resulted in about 4 N lower reading than when whole, non-bloated fruit was tested (Fleming and others 1995b). Bloater damage was determined based on the bloater index calculated by the method of Fleming and others (1977).

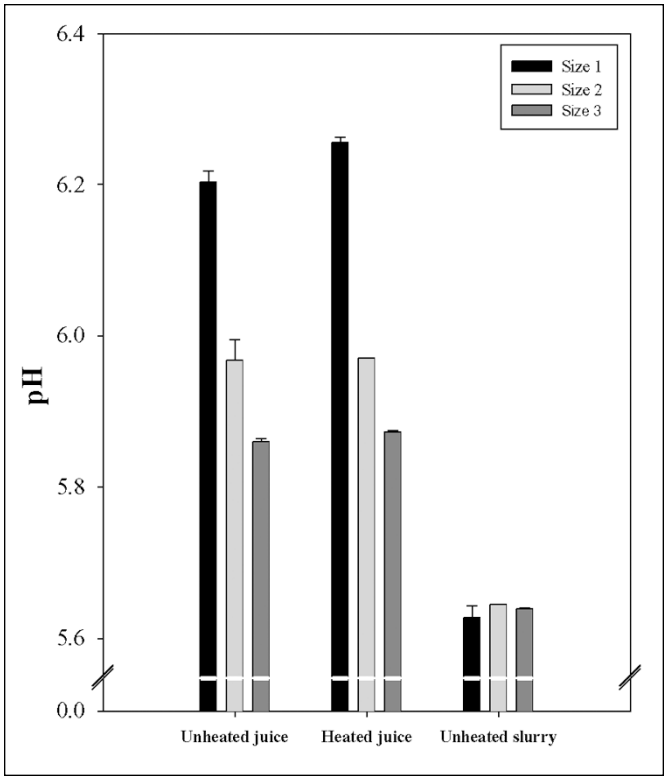

Figure 1—Natural pH of cucumber slurry and heated and unheated juices from 3 fruit sizes. The error bars show the standard deviations.

Statistical analyses

The experiment for determining pH and buffer capacity of cucumbers was a 2-factor 3 × 3 factorial design, with cucumber preparation and heat treatment as the factors. Another experiment for determining bloater formation was set up as a 2 × 3 factorial design with heat treatment and cucumber size as the factors. All statistical inferences were based on the statistics computed with the General Linear Model Procedure of SAS (SAS Institute, Inc., Cary, N.C., U.S.A.).

Results and Discussion

TABLE 1 SHOWS THE EFFECT OF CUCUMBER SIZE ON MALIC ACID, glucose, fructose, and dry matter content of Cross Country cultivar blend. As fruit size increased, malic acid content (wet basis) decreased slightly from 0.28 to 0.21%, while glucose and fructose contents (wet basis) increased from 0.80 to 1.16% and 0.95 to 1.25%, respectively. No other sugars were detected. The total sugar content (wet basis) in cucumbers was in the range of 1.7 to 2.4 %, depending on fruit size. Similar results were obtained by other investigators (McFeeters and others 1982; McCombs and others 1976).

The dry matter content of the cucumbers declined from 5.01 to 4.35% as fruit size increased. It is generally recognized that the number of cells in a cucumber fruit remains the same during enlargement and maturation. As a fruit gains weight (mainly water), nonwater constituents may not increase proportionately. Therefore, dry matter content (percentage) decreases as a fruit grows bigger. McCombs and others (1976) reported that dry mass content of cucumbers from fruit sizes 1, 2, and 3 ranged from 9.85 to 10.73%, which was more than 100% higher than what we obtained (4.3 to 5.0%), but the sugar content in their cucumbers (1.86 to 2.16%) was close to ours (1.75 to 2.40%). With the similar sugar content in cucumbers, it was unlikely that the dry mass content in their cucumbers could be more than 100% higher than ours. The data reported by McCombs and others (1976) later were found to contain a calculation error and should be 4.93 to 5.37% (D.M. Pharr, personal communication, 2001), which is consistent with our data.

The natural pH values of cucumber juice and slurry are shown in Figure 1. The pH of cucumber juice declined as fruit size increased. The pH values of unheated and heated juices from size 1 fruit were 6.20 and 6.26, respectively, significantly ($P < 0.05$) higher than those of juices from cucumbers of sizes 2 and 3 (5.86 to 5.97). Unexpectedly, all slurries regardless of fruit size had similar pH values (5.63 to 5.64), which was much lower than that in any juice. It was not clear why juice had a higher pH than slurry. Perhaps acids were trapped in insoluble materials of the slurry and not completely released into the aqueous phase when juice was prepared from slurry.

Titration curves for changes in pH of samples from the 3 fruit

Table 2—Effects of fruit size and blanch treatment on cucumber juice and whole cucumber fermentations[a]

	Initial					Final						
Cucumber size	Glucose (mM)	Fructose (mM)	Malate (mM)	Acetate[b] (mM)	pH[c]	Glucose (mM)	Fructose (mM)	Lactate (mM)	Malate (mM)	Acetate[d] (mM)	Ethanol (mM)	pH
Juice												
1	24.4	29.0	11.6	65.0	4.90	1.3	2.1	131.0	11.1	84.4	0.0	3.50
2	31.6	34.8	9.0	65.0	4.83	5.4	0.0	131.5	9.0	83.6	0.0	3.44
3	35.3	38.2	8.7	65.0	4.83	6.1	0.0	131.5	8.7	81.3	0.0	3.40
Whole fruit–unblanched												
1						0.4	0.0	134.6	0.1	92.0	5.4	3.62
2						0.4	0.0	141.2	1.2	90.2	9.2	3.47
3						0.7	0.0	136.7	1.7	88.7	10.9	3.44
Whole fruit–blanched												
1						0.4	0.0	129.3	2.5	93.1	8.0	3.60
2						0.7	0.0	131.8	4.0	86.4	11.0	3.45
3						0.6	0.0	133.7	3.2	87.8	12.5	3.44

[a]Each value represents the mean of 3 independent samples.
[b]The initial acetate was added in the brine.
[c]The initial pH was adjusted with acetic acid.
[d]The final acetate included both added and produced acetate in each fermentation.

sizes were established and representatively shown by those obtained from unheated juice in Figure 2. The curves covered the range from pH 6.2 to 2.0. The curve for size 1 fruit was above those for sizes 2 and 3, which were overlapped with each other, indicating that size 1 fruit required more HCl to reduce its natural pH to any specific value within the range of pH 2.0 to 6.2 than size 2 or 3 fruit, and sizes 2 and 3 required the same amount of HCl.

The buffer capacities of juices and slurries are shown in Figure 3. Both juice and slurry from size 1 fruit had higher buffer capacity (4.0 to 4.6 meq) than sizes 2 and 3 (2.9 meq for juice, 3.4 meq for slurry). This was mainly due to the fact that size 1 fruit contains a higher concentration of malic acid, which is the major natural buffer component in cucumbers. In addition, since size 1 fruit had higher dry mass content but lower sugar content, its nonsugar content was higher than that in sizes 2 or 3. Those nonsugar substances, such as certain proteins and cell wall materials, may also contribute to buffer capacity. Juices from fruit sizes 2 and 3, regardless of heat treatment, had similar buffer capacity. This was probably because the fruit from sizes 2 and 3 were in similar physiological stages, with resulting similar compositions and buffer capacities. The buffer capacity of slurry was 0.4 to 0.5 meq higher than that of corresponding juice, suggesting that certain insoluble cell materials in slurry contributed to the total buffer capacity.

It was observed that flocculation occurred when juice was heat-

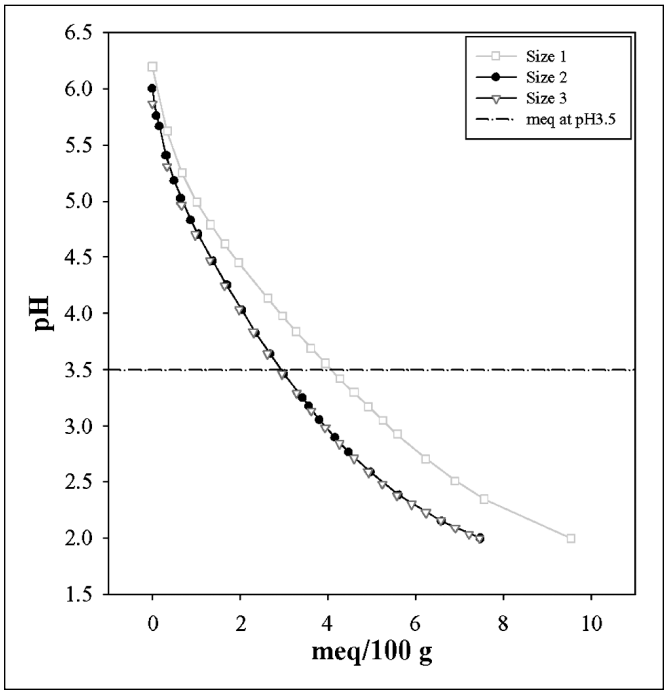

Figure 2—Titration curves of unheated cucumber juice from 3 fruit sizes. The horizontal dash-dot line (-•-) is drawn to facilitate the comparison of relative amounts of HCl required to reduce the natural pH of 100 g sample to pH 3.5.

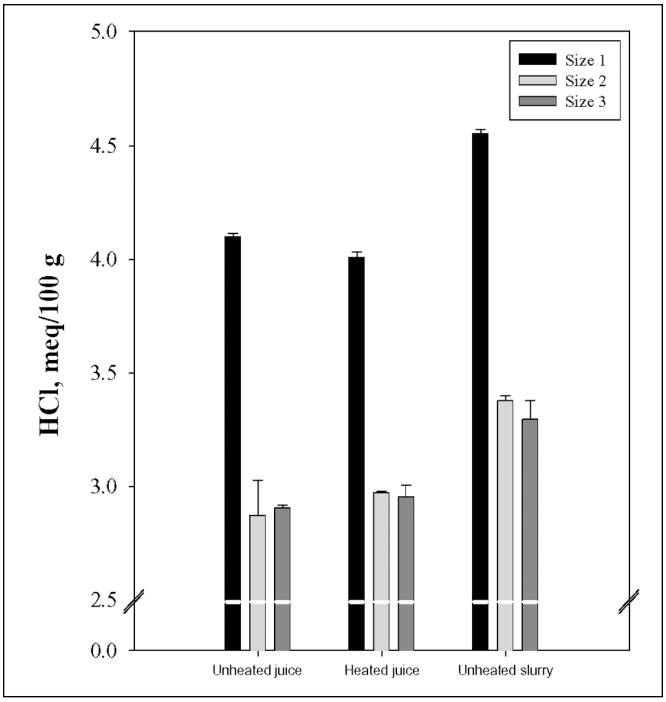

Figure 3—Buffer capacity of cucumber juice and slurry from 3 fruit sizes. Buffer capacity was defined as milliequivalents of HCl required to reduce the natural pH of 100 g sample to pH 3.5. The error bars show the standard deviations.

Table 3—Effects of blanch treatment[a] on firmness and bloater damage of fermented cucumbers[b]

Fruit size	Firmness (N)x		Bloater index	
	Unblanched	Blanched	Unblanched	Blanched
1	51.6 ± 9.8	72.5 ± 8.5	0.3 ± 0.6	0.0 ± 0.0
2	62.7 ± 9.8	79.2 ± 8.9	1.8 ± 1.1	2.8 ± 2.6
3	72.1 ± 9.8	75.6 ± 8.9	10.5 ± 3.1	10.5 ± 3.4

[a]Blanch treatment was conducted at 75 °C for 30 s.
[b]Each value represents the mean ± standard deviation of 3 independent fermentations.

ed. However, since heated and unheated juices had almost the same pH and buffer capacity, the precipitates during heating might not be acids or buffer agents or, even if they were, their quantities might be too small to affect the pH and buffer capacity of juice. Flocculation was also observed during titrating unheated juice with HCl. In contrast, heated juices remained clear throughout the titration even when pH decreased to 2.0, suggesting that the substances which could be precipitated by HCl were already removed from juice during heating. These substances were likely to be soluble proteins which were sensitive to both heat and acid.

Table 2 shows the effects of fruit size and blanch treatment on juice and whole cucumber fermentations. Initially, the natural concentrations of glucose, fructose, and malic acid varied according to fruit size, and all fermentations had the same amount of added calcium acetate buffer and similar pH (4.83 to 4.90) which was adjusted with acetic acid. In juice fermentations, glucose was not completely utilized (Table 2). As fruit size increased from 1 to 3, the concentration of residual glucose increased from 1.3 to 6.1 mM. Residual fructose (2.1 mM) was also present in the juice fermentation from size 1 fruit, but not in other fermentations. It was noted that the starter culture was able to utilize more fructose than glucose in all juice fermentations, suggesting different control mechanisms were involved in the utilization of the 2 sugars (Lu and others 2001a; 2001b). The growth of the starter culture was similar in all 3 juices and consistent with the data reported by Lu and others (2001a). Growth ceased after 40 h of fermentation mainly due to low pH resulting from lactic acid production.

The same amount (131 mM) of lactic acid was produced in all juice fermentation, regardless of fruit size. The concentration of natural malic acid remained unchanged in juice fermentations, indicating that the juice was fermented exclusively by the added starter culture which was unable to utilize malic acid. Acetic acid (16 to 19 mM) was also produced in juice fermentations, indicating that the starter culture did not remain 100% homofermentative. Murphy and others (1985) showed that the fermentation by *L. plantarum* shifted from homolactic to heterolactic when oxygen was present in the medium. The production of acetate might also suggest that a small amount of pentoses might be present in cucumber juice, although not detected in the study. *L. plantarum* can metabolize pentose heterofermentatively to acetic and lactic acids (Raccach and Marshall 1985). No ethanol was produced in any juice fermentation. As the fruit size increased, the terminal pH of juice fermentations decreased slightly from 3.50 to 3.40. This could be explained by our observation that larger fruit had lower buffer capacity.

Compared with juice fermentations, whole cucumber fermentations produced 3 to 9 mM more acetic acid (Table 2). Size 1 fruit seemed to result in slightly more acetate in all cases. Whole cucumber fermentations also produced about 5 to 12 mM ethanol. More ethanol was produced from larger fruit. Unblanched cucumber fermentations produced slightly less ethanol than blanched. The production of acetic acid and ethanol in whole cucumber fermentations was due apparently to the presence of some heterofermentative lactic acid bacteria on the fruit, which was consistent with the observation of increased pressure on jar caps, presumably due to CO_2 production (data not shown). Ethanol could also be produced from anaerobic respiration of the cucumber tissue or by yeasts if they were present on the fruit. Whole cucumber fermentation had slightly higher terminal pH than corresponding juice fermentation due to higher buffer capacity of whole fruit. But overall, the data in Table 2 showed that the results from whole cucumber fermentation were similar to those from cucumber juice fermentation. However, juice fermentation could not provide information on the texture of fermented cucumbers.

Blanch treatment had little effect on sugar utilization, acid production, and terminal pH in cucumber fermentations. Little glucose and no fructose were present at the end of whole cucumber fermentations, regardless of fruit size. This was probably because slurry, representing whole cucumbers, had higher buffer capacity than juice. Therefore, the starter culture encountered less acid stress, resulting in more complete sugar utilization. The slightly higher terminal pH observed in whole cucumber fermentation than in corresponding juice fermentation supported the explanation. The concentration of natural malic acid decreased in whole cucumber fermentations due to the presence of some natural flora, which was able to utilize malic acid. It was noted that slightly less malic acid was utilized in blanched than in unblanched cucumber fermentation because blanch treatment reduced the number of natural flora (Breidt and others 2000). Blanched and unblanched cucumber fermentations had almost the same terminal pH, ranging from 3.44 to 3.62. Similar to juice fermentation, larger fruit led to a slightly lower final pH. However, different observations were made by Jones (1940) who reported that the smaller sizes favored the development of greater acidity.

All fermented cucumbers looked normal and stable after 1 yr of storage. However, the firmness of the products and the bloater damage differed according to fruit size and/or blanch treatment (Table 3). Fermented products from fruit sizes 2 and 3 without blanch treatment were significantly firmer ($P < 0.05$) than those from size 1. The difference in firmness between sizes 2 and 3 fruit was not significant ($P > 0.05$). Generally, sizes 2 and 3 fruit had similar tough skins which contributed to their firmness. Blanch treatment prior to fermentation significantly increased firmness retention of the fermented products from sizes 1 and 2, but not size 3. Perhaps surface contamination by softening enzymes from microorganisms was greater on smaller fruit, as has been shown (Etchells and others 1958) and rendered the fruit more responsive to the blanch treatment. The bloater damage of fermented products was expressed as bloater index and shown in Table 3. The bloater indexes for fruit size 3 were significantly higher ($P < 0.05$) than those for smaller sizes (1 or 2). This probably resulted from the structural difference between sizes. Generally, the seed area in larger fresh cucumbers was softer than that in smaller fruit, thereby more susceptible to bloater damage. No significant differences in bloater indexes were found between products from blanched and unblanched cucumber fermentations from corresponding fruit sizes, indicating that blanch treatment at 75 °C for 30 s was not effective for bloater prevention. Perhaps higher blanching temperature or longer blanching time was needed to eliminate all gas-producing microflora on the fruit and/or to completely inactivate respiratory activity of the flesh. Further study is needed to investigate the effects of combinations of blanching temperatures and times on microbial survival and the prevention of bloater formation. Also, it

would be useful to confirm findings in this study with various cucumber cultivars.

Conclusions

THE CURRENT STUDY HAS REVEALED HOW CHEMICAL COMPOSITION of pickling cucumbers may influence fermentation and final composition of the stored product before processing into finished goods. Larger fruit contain higher levels of sugar, which will require more added buffer (such as calcium acetate) to assure complete sugar utilization. Smaller fruit, however, contain less sugar and a higher natural buffering capacity than larger ones. Excessive added buffer to the cover brine of the smaller fruit may result in an excessively high terminal pH, allowing secondary spoilage fermentation (Fleming and others 1989). This information will be useful in developing commercial brining strategies, including cover brine composition for different fruit sizes.

References

Andersson RE, Daeschel MA, Ericksson CE. 1988. Controlled lactic acid fermentation of vegetables. In: Durand G, Bobichon L, Florent J, editors. 8th International Biotechnology Symposium Proceedings. Vol. II. Paris, France: Societe Francaise de Microbiologie. P 855-868.

Bell TA, Etchells JL, Jones ID. 1955. A method for testing cucumber salt-stock brine for softening activity. USDA-ARS-72-5. 15 p.

Bell TA, Etchells JL. 1961. Influence of salt (NaCl) on pectinolytic softening of cucumbers. J Food Sci 26:84-90.

Breidt F, Hayes JS, Fleming HP. 2000. Reduction of microflora of whole pickling cucumbers by blanching. J. Food Sci 65:1354-1358.

Daeschel MA, McFeeters RF, Fleming HP, Klaenhammer TR, Sanozky RB. 1984. Mutation and selection of *Lactobacillus plantarum* strains that do not produce carbon dioxide from malate. Appl Environ Microbiol 47:419-420.

Daeschel MA, Fleming HP, McFeeters RF. 1988. Mixed culture fermentation of cucumber juice with *Lactobacillus plantarum* and yeasts. J Food Sci 53:862-864, 888.

Etchells JL, Bell TA, Monroe RJ, Masley PM, Demain AL. 1958. Populations and softening enzyme activity of filamentous fungi on flowers, ovaries, and fruit of pickling cucumbers. Appl Microbiol 6:427-440.

Etchells JL, Costilow RN, Anderson TE, Bell TA. 1964. Pure culture fermentation of brined cucumbers. Appl Microbiol 12:523-535.

Fleming HP.1982. Fermented vegetables. In: Rose AH, editor. Economic microbiology. Fermented foods. Vol. 7. New York: Academic Press, Inc. P 227-258.

Fleming HP, Thompson RL, Etchells JL, Kelling RE, Bell TA. 1973. Bloater formation in brined cucumbers fermented by *Lactobacillus plantarum*. J Food Sci 38:499-503.

Fleming HP, Thompson RL, Bell TA, Monroe RJ. 1977. Effect of brine depth on physical properties of brine-stock cucumbers. J Food Sci 42:1464-1470.

Fleming HP, Thompson RL, Bell TA, Hontz LH. 1978. Controlled fermentation of sliced cucumbers. J Food Sci 43:888-891.

Fleming HP, McFeeters RF, Daeschel MA, Humphries EG, Thompson RL. 1988. Fermentation of cucumbers in anaerobic tanks. J Food Sci 53:127-133.

Fleming HP, Daeschel MA, McFeeters RF, Pierson MD. 1989. Butyric acid spoilage of fermented cucumbers. J Food Sci 54:636-639.

Fleming HP, McFeeters RF, Daeschel MA. 1992. Fermented and acidified vegetables. In: Vanderzant C, Splittstoesser DF, editors. Compendium of methods for the microbiological examination of foods. Washington, D.C.: American Public Health Association. P 929-952.

Fleming HP, Kyung KH, Breidt F. 1995a. Vegetable fermentations. In: Rehm HJ, Reed G, editors. Biotechnology. Enzymes, biomass, food and feed. 2nd ed. New York: VCH Publishers, Inc. P 629-661.

Fleming HP, McDonald LC, McFeeters RF, Thompson RL, Humphries EG. 1995b. Fermentation of cucumbers without sodium chloride. J Food Sci 60:312-315, 319.

Fleming HP, Thompson RL, McFeeters RF. 1996. Assuring microbial and textural stability of fermented cucumbers by pH adjustment and sodium benzoate addition. J Food Sci 61:832-836.

Jones ID. 1940. Salting of cucumbers: Influence of brine salinity on acid formation. Ind Eng Chem 32:858-861.

Jones ID, Veldhuis MK, Etchells JL, Veerhoff O. 1940. Chemical and bacteriological changes in dill pickle brines during fermentation. Food Res 5:533-547.

Jones ID, Etchells JL, Veerhoff O, Veldhuis MK. 1941. Observations on bloater formation in cucumber fermentation. Fruit Prods J 20:202-206, 219-220.

Lu Z, Fleming HP, McFeeters RF. 2001a. Differential glucose and fructose utilization during cucumber juice fermentation. J Food Sci 66:162-166.

Lu Z, Fleming, HP, McFeeters RF. 2001b. Effects of anions and cations on sugar utilization in cucumber juice fermentation. J Food Sci 67:1155-1161.

McCombs CL, Sox HN, Lower RL. 1976. Sugar and dry matter content of cucumber fruits. HortScience 11:245-247.

McCreight JD, Lower RL, Pharr DM. 1978. Measurement and variation of sugar concentration of pickling cucumber. J Amer Soc Hort Sci 103:145-147.

McDonald LC, Shieh D-H, Fleming HP, McFeeters RF, Thompson RL. 1993. Evaluation of malolactic-deficient strains of *Lactobacillus plantarum* for use in cucumber fermentations. Food Microbiol 10:489-499.

McFeeters RF. 1993. Single-injection HPLC analysis of acids, sugars, and alcohols in cucumber fermentations. J Agric Food Chem 41:1439-1443.

McFeeters RF, Fleming HP, Thompson RL. 1982. Malic and citric acids in pickling cucumbers. J Food Sci 47:1859-1861, 1865.

McFeeters RF, Lovdal LA. 1987. Sugar composition of cucumber cell walls during fruit development. J Food Sci 52:996-1001.

Murphy MG, O'Connor L, Walsh D, Condon S. 1985. Oxygen-dependent lactate utilization by *Lactobacillus plantarum*. Arch Microbiol 141:75-79.

Passos FV, Fleming HP, Ollis DF, Hassan HM, Felder RM. 1993. Modeling the specific growth rate of *Lactobacillus plantarum* in cucumber extract. Appl Microbiol Biotechnol 40:143-150.

Passos FV, Fleming HP, Ollis DF, Felder RM, McFeeters RF. 1994. Kinetics and modeling of lactic acid production by *Lactobacillus plantarum*. Appl Environ Microbiol 60:2627-2636.

Passos FV, Fleming HP, Felder RM, Ollis DF. 1997. Modeling growth of Saccharomyces rosei in cucumber fermentation. Food Microbiol 14:533-542.

Pharr, DM. 2001. Personal communication.

Pharr DM, Sox HN, Smart EL, Lower RL. 1977. Identification and distribution of soluble saccharides in pickling cucumber plants and their fate in fermentation. J Amer Soc Hort Sci 102:406-409.

Raccach M, Marshall PS. 1985. Effect of manganese ions on the fermentative activity of frozen-thawed lactobacilli. J Food Sci 50:665-668.

Sneed FD, Bowers JL. 1970. Green fruit characters of cucumber as related to quality factors in brine stock. J Amer Soc Hort Sci 95:489-491.

[USDA] U.S. Dept. of Agriculture. 1998. USDA nutrient database for standard reference in cucumber, with peel, raw. Washington, D.C.: USDA Food Composition Data. Available from: http://www.nal.usda.gov/fnic/cgi-bin/list_nut.pl. Accessed 3/15/99.

Veldhuis MK, Etchells JL, Jones ID, Veerhoff O. 1941. Influence of sugar addition to brine in pickle fermentation. Food Ind 13:54-56.

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