FACTORS INFLUENCING BLOATER FORMATION IN BRINED CUCUMBERS DURING CONTROLLED FERMENTATION

INTRODUCTION

BLOATER DAMAGE in commercially brined cucumbers, particularly the larger sizes, is a source of serious economic loss to the pickle industry. The recent advent of mechanical harvesting, which favors harvest of larger sizes, combined with the increased demand for larger-sized brine-stock for making hamburger dill chips, dill spears, relishes, etc., has increased the need for reduction of bloater development.

The successful pure culture fermentation of cucumbers, which had been heat-shocked (77°C, 5 min) and brined in containers ranging from 1 qt to 5 gal, by certain lactic acid bacteria (Etchells et al., 1964, 1968a), encouraged us to consider adapting the process for commercial brining in bulk containers. Heating to rid green-stock of contaminating microbes was considered impractical for bulk-brining in commercial tanks. Alternatively, a procedure not requiring use of heat was used which afforded a means of obtaining a desired fermentation, predominated by *Lactobacillus plantarum*. This procedure, developed over several years, included thorough washing of the green-stock; chlorination of the cover brine; acidification; buffering; and inoculation with *L. plantarum*. The equilibrated brine strength and temperature were carefully controlled according to Etchells and Hontz (1972).

Serious bloater damage resulted, however, when the above procedure was used, due to the small amounts of CO_2 produced by *L. plantarum* and the respiring cucumbers (Fleming et al., 1973a, b). This illustrated that bloater formation can occur under certain conditions even with a homofermentative lactic acid bacterium; gas-forming microbes such as yeasts, coliforms and heterofermentative lactics do not necessarily have to be present for bloater damage to occur as was previously thought. Purging of dissolved CO_2 from the brine with nitrogen resulted in essentially bloater-free brine-stock cucumbers (Fleming et al., 1973a).

Based on these findings, a "controlled fermentation" process was outlined for use by commercial briners (Etchells et al., 1973). A fermentation predominated by *L. plantarum*, and purging of CO_2 from the brine with nitrogen are two primary features in the process.

The present study preceded the outlined process of Etchells et al. (1973), and served as a basis on which the process was founded. CO_2 was not purged from the brines in the present work. Rather, our objective was to study environmental factors which influence bloater formation in nonpurged fermentations predominated by *L. plantarum*, including brining depths, pack-out ratio and temperature. Also, comparisons of chemical and microbiological changes in natural and controlled (i.e., predominated by *L. plantarum*) fermentations illustrate basic problems encountered in the development of the controlled fermentation process, particularly in relation to directing the fermentation.

MATERIALS & METHODS

SIZE NO. 3, pickling cucumbers (1-1/2–2 in. diam), hand-harvested, were brined in epoxy-coated, 55-gal, steel drums using essentially the same basic brining procedure described earlier for controlled fermentation of cucumbers brined in bulk (Etchells and Hontz, 1972; Etchells et al., 1973). Briefly, this procedure, with some modifications necessary for present objectives, was as follows: cucumbers were thoroughly washed, preshrunk in 25° salometer brine containing 80 ppm available chlorine for 2–3 hr, or until the cucumbers were sufficiently flaccid to obtain a pack-out ratio of cucumbers:brine on a percentage by wt basis of 65:35, or 270 lb cucumbers and 17.5 gal brine for a "full" drum (50 gal). This brine was drained off and replaced with fresh 25° salometer, chlorinated brine, to which was added 6 ml of glacial acetic acid per gallon of brined cucumbers. The cucumbers were kept immersed in the brine by means of a perforated, 1/4-in. thick, flat, plastic "false head" mounted inside the top of the drums, at the 50 gal mark, and about 1–2 in. below the brine surface. Chlorinated nylon cloth or a large, circular piece of filter paper was placed on the "false head;" then, the desired amount of dry salt was carefully added to maintain the brine strength at 25° salometer. The salt was added on the head at the rate of 6 lb per 100 lb cucumbers; 1/2–2/3 was added immediately after heading (and brining) and the remainder about 24 hr later. Sodium acetate (3 H_2O), sufficient to equilibrate at 0.5%, was added to the head about 18 hr after brining.

The initial pH of the acidified cover brine was about 2.8. The pH rose during the 24-hr equilibration as acetic acid diffused from the cover brine into the cucumbers. With the addition of sodium acetate, several hours prior to inoculation, the brine was buffered at pH 4.7 (± 0.2), which is suitable for growth of *L. plantarum*. The brine has consistently shown no visual turbidity after 1–2 days' equilibration with the cucumbers prior to inoculation.

The brine-cucumber-mass was next inoculated with a frozen (liquid nitrogen) culture concentrate of *L. plantarum* (Chr. Hansen's Lab., Inc., Milwaukee, Wisc.) at a concentration of about 4 billion cells/gal of brined material about 24 hr after brining. In some instances, we have used inocula prepared by growing the cultures in cucumber juice broth (CJB; Fleming and Etchells, 1967).

The times for salt and acetate additions, and inoculation were extended up to 12 hr longer in some instances, depending on characteristics of the cucumbers, so that the brine strength would be below 28° (7.4%/wt) salometer before addition of the second salt and before inoculation. In all instances, however, the sequence of additions was the same.

The 55-gal drums were incubated in "walk-in," controlled-temperature rooms, located at a cooperating pickling plant, or in the Food Science building at North Carolina State University. Low-ozone ultraviolet (2537 Angstroms) germicidal lamps (Atlantic Ultraviolet Corp., Long Island City, N.Y.) were placed 20 in. directly above the uncovered brine surface to prevent growth of film yeasts. Alternatively, in some drums, film yeasts were inhibited by placing about 1-in. diam, plastic bubbles (cut from packing material), containing mustard oil, on the brine surface. Vapor from the mustard oil escaped gradually through the needle puncture made when the oil was injected by syringe into the bubbles. Plastic sheeting was loosely draped over each drum to retard loss of mustard oil vapor, but allow the more volatile CO_2 to escape and thereby prevent a build-up of pressure.

Evaluation of the brine-stock for bloater damage, determined 2–3 wk after brining, and methods for titratable acidity (calculated as lactic acid), pH, NaCl and reducing sugars were those described or referred to

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Table 1—Populations and isolation of lactic acid bacteria in controlled and natural fermentations of brined cucumbers[a]

	Controlled			Natural		
		Isolates			Isolates	
Days after brining	Lactic acid bacteria (Millions/ml)	No. picked	No. gas formers[b]	Lactic acid bacteria (Millions/ml)	No. picked	No. gas formers[b]
1	0.03[c]	15[c]	14[c]	1.08	—	—
2	8.5	12	0	12.5	—	—
3	265.0	12	0	13.5	12	4
4	185.0	9	0	40.5	9	0
5	93.0	9	0	12.0	11	1
7	17.6	9	0	1.6	12	0
9	2.2	9	0	0.5	12	1
12	0.4	9	0	0.06	12	1
14	5.8	9	0	4.4	12	2
20	0.03	9	0	2.4	9	1

[a] See Materials & Methods for brining procedures. Lactic counts for controlled and natural fermentations were from single, 55-gal drums of each. The controlled fermentation was inoculated 1 day after brining. Incubation, 27°C.
[b] Number of gas-formers out of the total number of isolates picked from LBS agar plates
[c] This sample was taken immediately prior to inoculation.

previously (Fleming et al., 1973a). Dissolved CO_2 was determined by the method of Fleming et al. (1974). Samples were taken with sterile 12-ml disposable syringes through rubber serum stoppers, positioned at appropriate locations in the side of the drum. All values reported are averages of duplicate fermentations unless otherwise indicated.

Media used for plate counts of the various microbial groups were: LBS medium (BBL), for lactic acid bacteria (Rogosa et al., 1951, as modified by Costilow et al., 1964); dextrose agar (BBL), acidified with 5 ml of 5% tartaric acid/100 ml medium immediately before pouring, for yeasts; and violet red bile agar (BBL), for coliform bacteria. Incubation was at 30°C for lactics and yeasts, and 37°C for coliforms.

For isolation of lactic acid bacteria, colonies were picked from LBS plates, transferred to CJB tubes and incubated at 30°C. Cell morphology was determined microscopically at 1350X magnification under an oil immersion objective. Final pH, acidity and residual reducing sugars were determined after 2 wk incubation of the isolates. These data were used as supporting evidence in classifying the isolates.

Heterofermentative (gas-forming) lactic acid bacteria were determined by a modification of the general procedure of Gibson and Abdel-Malek (1945). A drop of an active broth culture of each isolate was transferred to 5 ml of CJB with 2% NaCl in 19 × 100 mm tubes. 2 ml of sterile petrolatum were added to each tube, which was then loosely capped with a Bacti-capall (Preiser Scientific). Heterofermentative lactic acid bacteria, *Lactobacillus brevis* and *Leuconostoc mesenteroides*, produced sufficient CO_2 after 3 days at 30°C to force the petrolatum upwards, leaving a gas pocket. Homofermentative bacteria, *L. plantarum* and *Pediococcus cerevisiae*, did not produce enough CO_2 to form a gas pocket. This test for gas formation was verified by using pure cultures of the above-named species.

RESULTS

Comparison of controlled and natural fermentations

In the controlled fermentation process (Etchells et al., 1973) applied in the present experiments, except without purging, fermentation by the added starter culture, *L. plantarum*, predominated. Brines from cucumbers which had been chlorinated and acidified according to this process contained only 350 coliform bacteria per ml 1 day after brining and just before inoculation with *L. plantarum;* none was detected 1 day after inoculation and thereafter. In contrast, a natural fermentation contained 15,000 coliform bacteria per ml 1 day after brining, but the count dropped to about 100/ml after 3 days, and none was detected thereafter. Yeast counts were 50–100/ml in both fermentations during the first 3 days, and were less than 100/ml thereafter until 7 days when a slight growth of film yeast began in a small area of the brine surface shaded from UV light. Coliform and yeast counts in brines of natural fermentations are variable, and should be expected to deviate widely from the examples above.

One day after brining, populations of lactic acid bacteria in the brines of unwashed cucumbers (natural fermentation) were 36X those of brines from washed-chlorinated-acidified (controlled fermentation) cucumbers before inoculation (Table 1). The lactic count reached a maximum of 265×10^6 cells/ml 2 days after inoculation of the controlled fermentation and then declined. Maximum lactic count in the natural fermentation, 40.5×10^6 cells/ml, was reached 4 days after brining.

Prior to inoculation, lactic isolates from the brines of controlled fermentations were practically all gas-formers, cocci or short rods, single and in chains, and similar to species in the genus *Leuconostoc*. After inoculation, isolates were all nongas-formers (Table 2) and short rods typical of the *L. plantarum* starter culture. Isolates from the natural fermentation over a 20-day period were about 86% nongas-forming lactobacilli, 9% gas-forming lactobacilli, 2% leuconostocs and 2% pediococci

Table 2—Isolation of lactic acid bacteria from controlled and natural fermentations of brined cucumbers[a]

	Controlled	Natural	
Isolate type	No. of isolates[b]	No. of isolates	Time of isolation[c]
Total	87	89	3–20 days
Leuconostoc sp.	0	2	3rd day
Lactobacillus sp.			
Non-gas-formers	87	77	3–20 days
Gas-formers	0	8	3–20 days
Pediococcus sp.	0	2	3rd & 5th days

[a] Isolates were picked from colonies of LBS agar platings of brine samples taken from the controlled and natural fermentations represented in Table 1.
[b] Refers to number of isolates taken after inoculation and 2–20 days after brining.
[c] Refers to time after brining the cucumbers

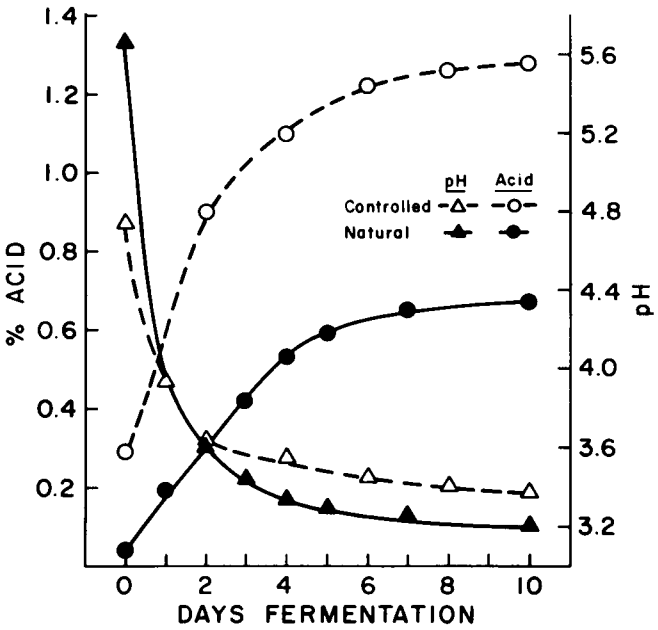

Fig. 1—Acid production in controlled and natural fermentations of brined cucumbers. Initial values obtained 1 day after brining and just prior to inoculation.

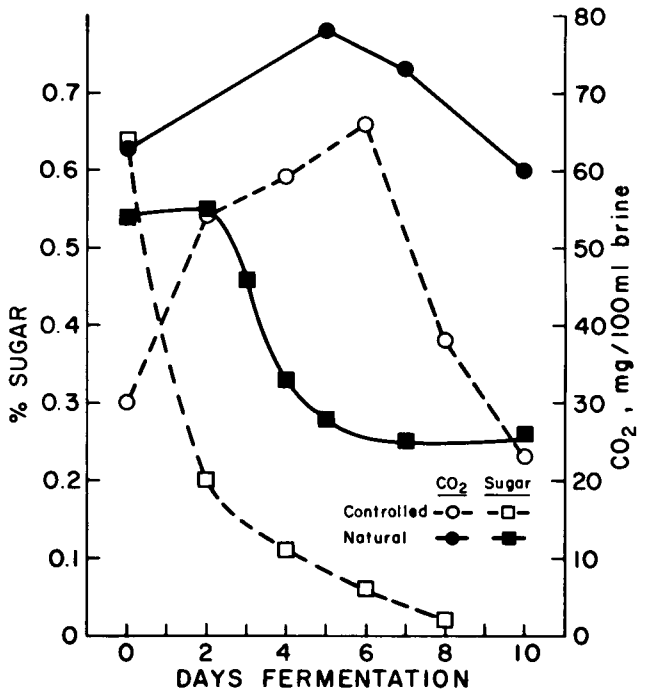

Fig. 2—Sugar utilization and CO_2 production in controlled and natural fermentations of brined cucumbers. Initial values obtained 1 day after brining and just prior to inoculation.

(Table 2); gas-forming lactobacilli were isolated throughout the 20-day period.

In controlled fermentations of brined cucumbers incubated at 32°C and 25° salometer, fermentable sugars were rapidly and completely converted to acid, usually within 7–10 days (Fig. 1 and 2). The amount of sodium acetate added provided sufficient buffering action to permit *L. plantarum* to ferment all of the brine sugars which diffused from the cucumbers. After completion of fermentation, the pH was 3.3–3.4, which is above the range that inhibits the *L. plantarum* culture used. Criteria used to determine completion of fermentation were: absence of reducing sugars and of changes in titratable acidity and pH over a 2-day interval between analyses.

In natural fermentations, times required for conversion of sugars to acid were longer and unpredictable in comparison with controlled fermentations. About 0.25% sugar remained after the production of lactic acid had ceased (Fig. 1 and 2). In this particular case, the pH had dropped to 3.2 and further activity by the natural lactic acid bacteria was inhibited. Residual sugars in such instances usually are fermented by subsurface yeasts with resulting bloater formation (Etchells and Bell, 1950; Etchells et al., 1952, 1953). We have observed some natural fermentations in which all sugars were metabolized as rapidly as in controlled fermentations, and others in which fermentation ceased when up to 0.5% sugar, still remained. We attribute such variation in natural fermentations to the variability in populations of natural microflora that convert sugar to carbon dioxide, acetic acid, various alcohols, etc., in addition to lactic acid. Coliform bacteria, heterofermentative lactic acid bacteria and yeasts contribute to this

Table 3—Bloater formation and brine analyses of controlled and natural fermentations of brined cucumbers

	Bloater damage[a]							Brine analyses[b]			
	Balloon		Lens		Honeycomb		Total		Acid	Sugar	Maximum CO_2
Treatment	%	D	%	D	%	D	%	pH	%	%	mg/100 ml
Controlled											
32° C	22.0	(A-M)	9.5	(M)	16.5	(M-S)	48.0	3.34	1.32	0.02	68.5
27° C	10.0	(S)	8.0	(S)	6.5	(S)	24.5	3.38	1.30	0.00	66.5
Natural											
32° C	59.0	(A)	24.0	(A)	10.5	(M)	93.5	3.26	0.65	0.26	79.5
27° C	50.0	(A)	27.5	(A)	12.5	(M-S)	90.0	3.28	0.62	0.08	91.5

[a] Capital letters in parentheses under "D" in Table refer to severity of bloating: S = Slight, M = Moderate and A = Advanced condition. When two letters appear, the first indicates the category in which most of the damage was placed. Values are averages of duplicate fermentations.

[b] Analyses after 10 days' fermentation, except for maximum CO_2 values which usually occurred 4–6 days after inoculation. Values are averages of duplicate fermentations.

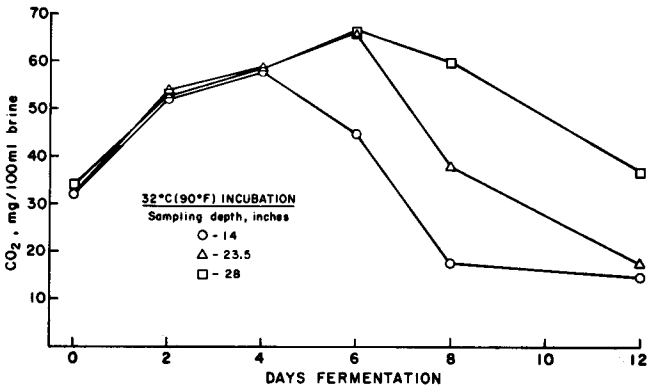

Fig. 3—Concentrations of dissolved CO_2 at various depths in full drums of brined cucumbers undergoing controlled fermentation at 32° C. Initial values obtained 1 day after brining and just prior to inoculation.

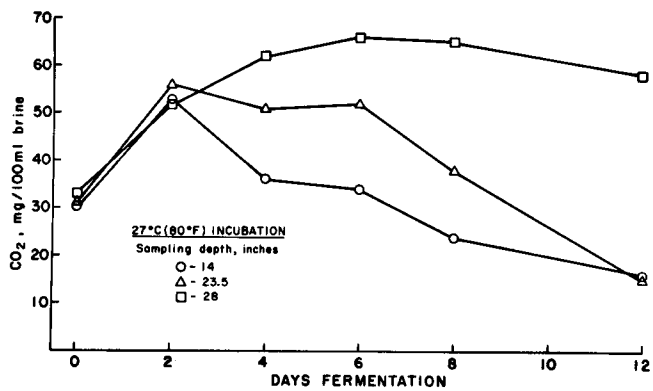

Fig. 4—Concentrations of dissolved CO_2 at various depths in full drums of brined cucumbers undergoing controlled fermentation at 27° C. Initial values obtained 1 day after brining and just prior to inoculation.

variability. Also, cucumbers vary in their contents of fermentable sugars; those with high amounts (particularly large sizes), usually are not fully fermented by the lactic acid bacteria in an unbuffered brine (Etchells and Moore, 1971).

Bloater damage occurred in the controlled fermentations (Table 3), although it was much less than in natural fermentations (Table 3). Furthermore, bloater damage was less at 27°C than at 32°C for both controlled and natural fermentations. Carbon dioxide content of the brine reached and maintained higher levels in natural than in controlled fermentations (Fig. 2). This probably accounts for the higher incidence and severity of bloater damage in the natural fermentations.

Brining to various depths

Cucumbers were brined in 55-gal drums at three levels of fill, with the pack-out ratio (i.e., cucumbers:brine) remaining constant at 65:35% by wt. Thus, only the depth of the cucumber-brine-mass varied.

Bloater damage when cucumbers were brined to a depth of 27 in. (full drum; 50 gal at head level), 18 in. (2/3 full), and 9 in. (1/3 full) is given in Table 4. Statistical evaluations of these data are summarized in Table 5. Examination of Table 5 shows that differences in percent bloaters due to "type" are significant, but none of the interactions with "type" are. The means in Table 4 show that "type" differences arise from the much higher incidence of balloon than either lens or honeycomb type. The lack of interactions with "type" suggests that the effects of temperature and depth of brining are essentially consistent for all bloater types. Hence, effects of temperature and depth of brining may be inferred from the means of percent total bloaters.

Bloater damage, whether expressed as percent affected or severity of those affected, was greater when cucumbers were brined at 32°C than at 27°C; and there was more damage in cucumbers brined at greater depths within each temperature (Table 4). The significant interaction of the linear effect of depth with temperature (Table 5) arises from the fact that the increase in bloaters at 32°C is much sharper than at 27°C. At 27°C the average increase in percent total bloaters is 5% for each 9-in. increase in depth; at 32°C this increase averages 18% (Table 4).

Table 4—Influence of brine depth and temperature on bloater formation in controlled fermentations of brined cucumbers[a]

Brine-cucumber-mass depth Inches	Bloaters[b]							Bloaters induced by mechanical damage[c]					Brine analyses[d]	
	Balloon		Lens		Honeycomb		Total	Balloon		Lens		Total	Acid	
	%	D	%	D	%	D	%	%	D	%	D	%	%	pH
32° C Incubation														
27	22.0	(A-M)	9.5	(M)	16.5	(M-S)	48.0	3.5	(S)	0		3.5	1.32	3.34
18	10.5	(M-A)	7.0	(M)	3.5	(M)	21.0	3.0	(S)	3.0	(S)	6.0	1.25	3.35
9	7.0	(M-S)	3.5	(S)	1.5	(S)	12.0	3.0	(S)	1.5	(S)	4.5	1.18	3.36
Average	13.2		6.7		7.1		27.0	3.2		1.5		4.7	1.25	3.35
27° C Incubation														
27	10.0	(S)	8.0	(S)	6.5	(S)	24.5	5.0	(S)	4.0	(S)	9.0	1.30	3.38
18	7.5	(M-S)	4.5	(S)	5.0	(M)	17.0	3.0	(M)	2.0	(M)	5.0	1.22	3.35
9	8.5	(S)	3.5	(S)	2.5	(S)	14.5	5.5	(S)	0		5.5	1.14	3.35
Average	8.7		5.3		4.7		18.7	4.5		2.0		6.5	1.22	3.36

[a] The pack-out ratio was constant for all treatments; 65% cucumbers, 35% brine, by weight. All values are averages of duplicate fermentations, except for the 9-in. depth which are averages of triplicates.
[b] Letters in parentheses indicate the severity of bloating; see footnote a, Table 3 for description.
[c] Bloaters induced by mechanical damage are also included with the normal bloaters which are given in the preceding columns.
[d] Values after 12 days' fermentation. Reducing sugars were less than 0.1% in all cases.

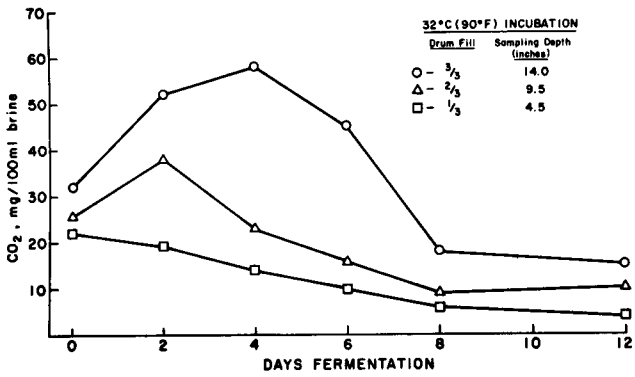

Fig. 5—Concentrations of dissolved CO_2 in brines of cucumbers undergoing controlled fermentation at various levels of container fill at 32° C. Samples were taken from mid-depth for each level of fill. Initial values obtained 1 day after brining and just prior to inoculation.

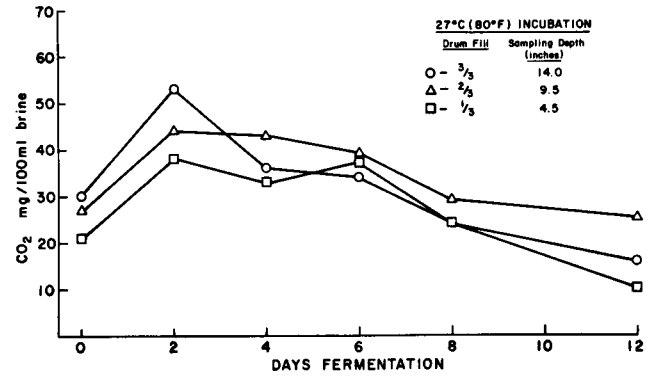

Fig. 6—Concentrations of dissolved CO_2 in brines of cucumbers undergoing controlled fermentation at various levels of container fill at 27° C. Samples were taken from mid-depth for each level of fill. Initial values obtained 1 day after brining and just prior to inoculation.

Concentrations of dissolved CO_2 at 3 depths in the full drums were monitored (Fig. 3 and 4). At both 32 and 27°C, concentration and retention of CO_2 were directly related to the depths from which samples were taken. At both temperatures, concentration of CO_2 reached a maximum at the greatest brine depths after about 6 days, and the values were similar, about 66 mg/100 ml brine. Over the next 6 days, however, the CO_2 concentration remained higher at 27°C than at 32°C.

CO_2 was also monitored at mid-depth of the three basic levels of container fill (Fig. 5 and 6). Concentrations of CO_2 were correspondingly lower in the brines of cucumbers packed at correspondingly more shallow depths.

Mechanical injury

For several years we have observed that brine-stock pickles of all sizes, showing clear-cut evidence of bruises from handling of the green-stock, are practically always bloated in and around the bruises. Bruises usually can be detected by cutting the raw cucumbers or partially-cured brine-stock at an injured area of the flesh. Here, the usual white, opaque, uncured stock is translucent around the bruise. Heretofore, we have not differentiated between bloaters that were associated with mechanical damage and those that were not. Table 4 indicates that bloaters associated with mechanical damage occurred with about the same relative frequency at all brining depths, at 32 and 27°C, whereas, the total percentage of cucumbers bloated was decidedly higher at 32°C. Mechanical harvesting causes more damage to cucumbers than hand harvesting (Marshall et al., 1972), and therefore may result in a higher incidence of bloater formation.

Brine circulation

Since CO_2 concentrations were lower near the brine surface exposed to the atmosphere (Fig. 3 to 6), we thought that circulation might help reduce the CO_2 concentration throughout the brine. Brine circulation did reduce CO_2 accumulation

Table 5—Analysis of variance for the effects of brine depth and temperature on bloater formation in cucumbers[a]

Source of variation	d.f.	Mean square
Bloater type	2	98.36**
Temperature	1	69.44**
Type X temperature	2	7.69
Depth (linear)	1	352.67**
Depth (deviation from linear)	1	29.39
Type X depth (linear)	2	9.54
Type X depth (deviation from linear)	2	4.85
Temp X depth (linear)	1	112.67**
Temp X depth (deviation from linear)	1	9.39
Type X temp X depth (linear)	2	20.04
Type X temp X depth (deviation from linear)	2	10.02
Pooled error	18	12.33

[a] Combined analysis made from orthogonal comparisons of replicate totals. See Table 4 for details of the experiment.
** Significant at the 0.01 level of probability.

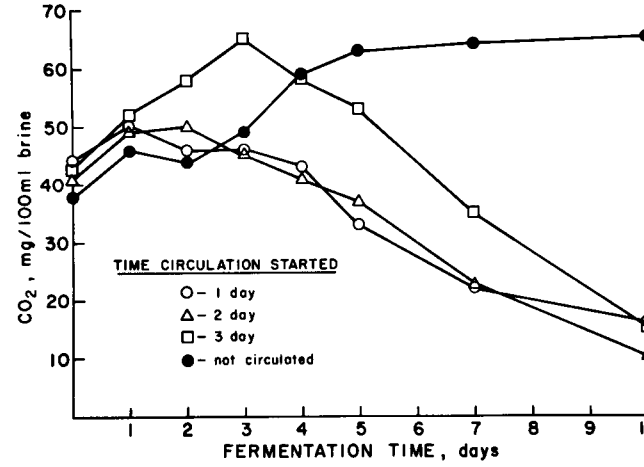

Fig. 7—Effect of brine circulation on CO_2 retention in brines covering cucumbers undergoing controlled fermentation at 27° C. (See footnote a, Table 6, for circulation treatment.) Values represent single drums. Initial values obtained 1 day after brining and just prior to inoculation.

Table 6—Influence of brine circulation on bloater formation

Time circulation started[a]	Bloater damage[b] Balloon %	D	Lens %	D	Honeycomb %	D	Total %	Maximum CO_2 mg/100 ml
32° C Incubation								
Uncirculated	36	(A)	27	(M)	15	(M)	78	56
1 Day	17	(A)	41	(M)	9	(M-S)	67	54
2 Day	20	(S-M)	24	(S-M)	12	(S)	56	59
3 Day	29	(A)	36	(M)	13	(S)	78	60
27° C Incubation								
Uncirculated	7	(S)	20	(S)	0	—	27	65
1 Day	7	(S)	20	(S)	0	—	27	50
2 Day	7	(S)	10	(S)	0	—	17	50
3 Day	17	(S)	11	(S)	1	(S)	29	65

[a] The brine was circulated, beginning on the day indicated, after inoculation, for 30 min twice a day at two, 12-hr intervals. A submerged pump circulated the brine up through a rubber tubing located inside a 3-in. diam, plastic pipe into a perforated, 12-in. diam, plastic bowl located above the brine surface, from which the brine trickled back into the drum. Circulation was at the rate of 3 gal/min.
[b] Values are from single drums from each treatment. Letters in parentheses indicate the severity of bloating; see footnote a, Table 3.

(Fig. 7), but not bloater damage (Table 6). A more efficient circulation system, particularly if started sooner, might reduce CO_2 in the brine enough to reduce bloater development.

Effect of pack-out

Cucumbers were brined at pack-out ratios (cucumbers: brine) of 65:35, 55:45 and 45:55% by wt. Bloater damage decreased at lower pack-out ratios (Table 7). Percents of total bloaters and balloon bloaters ($P < 0.01$) and honeycomb bloaters ($P < 0.05$) were significantly higher at 65:35 than at 45:55. Although CO_2 concentrations were not determined, the smaller proportion of cucumbers would be expected to give off less CO_2, which would be dissolved in greater amounts of brine. Furthermore, less brine sugars would be available for CO_2 production by microbial metabolism.

Table 7—Influence of pack-out ratio on bloater formation in controlled fermentation of brined cucumbers[a]

Pack-out ratio, by wt Cucumbers %	Brine %	Bloater damage[b] Balloon %	D	Lens %	D	Honeycomb %	D	Total %
65	35	20	(M)	2	(S)	32	(S-M)	54
55	45	17	(M-A)	0		18	(S-M)	35
45	55	10	(S-M)	0		9	(S)	19

[a] Incubation temperature, 30° C
[b] Letters in parentheses indicate the severity of bloating; see footnote a, Table 3, for description.

DISCUSSION

A BRINE FERMENTATION of cucumbers predominated by *L. plantarum* will not necessarily insure bloater-free brine-stock. Bloater damage is influenced by factors which favor retention in the brine-mass of the relatively small amounts of CO_2 produced in such fermentations.

The uncovered containers we used simulated commercial brining conditions. The maximal amount of CO_2 accumulated at any given time during fermentation in such containers depends on two opposing factors, namely, the rate at which CO_2 is formed, and the rate at which it diffuses into the atmosphere from the brine surface.

In a rapid fermentation during the first few days after the initial brining, microbial activity causes a rapid accumulation of CO_2, which, combined with CO_2 from the respiring cucumbers, may readily favor bloater formation. Thus, inoculation with a vigorous strain of a lactic acid species, even a homofermentative such as *L. plantarum*, may actually promote bloater development unless CO_2 is removed during this period by some means such as purging with nitrogen (Fleming et al., 1973a). Optimum temperature for growth of the culture might contribute to bloater formation. Also, higher temperatures reduce the solubility of CO_2 (Quinn and Jones, 1936); and, according to Boyle's gas law, gaseous CO_2 would either occupy more space and/or create a greater pressure at higher temperatures. Thus, CO_2 present inside the cucumber, might be forced from solution, increase gas pressure and cause a bloated area.

The depth of the cucumber-brine-mass influences the retention of dissolved CO_2, in uncovered containers. An increase in the ratio of exposed brine surface area to total volume of brine-cucumber-mass would be expected to decrease accumulation of CO_2. In cylindrical, uncovered brining tanks, depth is the primary geometrical dimension which influences CO_2 retention in the brine. Commercial cucumber brining tanks are essentially cylindrical, about 8–16 ft in diameter and 7–8 ft deep. Deep tanks would be expected to retain high concentrations of CO_2 for longer times than shallow tanks, especially near the bottom, and bloater damage may be greatest at the bottom. The manner in which head boards are placed on the top of the cucumbers could also be important. Tightly fitting head boards would restrict diffusion of CO_2 from the brine into the atmosphere. A more desirable procedure would probably be to allow spacing between or, better, to perforate the head boards (Etchells et al., 1973).

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