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SUSCEPTIBILITY OF PICKLING CUCUMBERS TO BLOATER DAMAGE BY CARBONATION

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ABSTRACT

The susceptibility of pickling cucumbers to bloater damage was studied by artificial carbonation of brined cucumbers with mixtures of CO_2 in N_2. Bloater damage was induced within a few hours by carbonation of heated and unheated cucumbers, independent of microbial growth, suggesting that a physical-chemical mechanism causes bloating. Evidence indicated, however, that biological factors may also influence bloating. Unheated, brined cucumbers bloated only slightly when carbonation was begun immediately after brining, or about a month or longer after brining. The cucumbers bloated extensively, however, when carbonation was begun between about 1 and 30 days after brining. Damage was more closely associated with % saturation than with concentration of dissolved CO_2. Serious bloater damage was prevented when CO_2 in brines was maintained below 50% saturation. Bloater damage resulted within a few hours, however, if brine CO_2 greatly exceeded this level. Cucumbers varied in tolerance to CO_2 before development of serious damage. The method herein reported for controlling levels of CO_2 in the brine may be useful in further study of factors that influence the susceptibility of cucumbers to bloater damage.

INTRODUCTION

THE TREND TO HARVEST larger cucumbers, brought on by increased mechanization, has resulted in increased bloater damage of cucumbers during brine preservation. Bloater damage, which is a greater problem in large than in small cucumbers, is associated with a build-up of dissolved CO_2 in the brine (Fleming et al., 1973a). The CO_2 may arise from the cucumber tissue and homofermentative lactic acid bacteria (Fleming et al., 1973b), as well as from microorganisms that produce large amounts of CO_2 (Etchells et al., 1945; Etchells and Bell, 1950; Etchells et al., 1968).

Purging CO_2 from brines greatly reduces bloater damage (Fleming et al., 1973a; 1975; Costilow et al., 1977), and is a principal feature in the controlled fermentation process introduced to industry (Etchells et al., 1973). Nitrogen gas is preferred for the purging treatment. Since purging is an expense to the brining operation, interest has developed in establishing the maximum tolerance, or "critical" level of CO_2 for bloater damage. Several factors influence this critical level including fermentation temperature and size of cucumbers (Fleming et al., 1973a; Samish et al., 1957), and probably mechanical injury of the cucumbers before brining (Marshall et al., 1973; Etchells et al., 1975). Cucumbers can tolerate higher dissolved CO_2 at a greater brine depth due apparently to greater hydrostatic pressure; buoyancy pressures on cucumbers near the top of the brine mass may cause mechanical injury and lead to greater bloater damage (Fleming et al., 1977).

Etchells et al., 1973, recommended that the dissolved CO_2 be maintained below 20 mg/100 ml brine to prevent bloater damage in large cucumbers. Although this level is probably safe under most conditions, it was not suggested that this was the maximum tolerance level. Commercial firms and scientists throughout the United States have tested a variety of devices for mechanically removing CO_2 from brines. Information is lacking, however, on the tolerance of cucumbers to CO_2 under various environmental conditions and at different stages during brining.

Objectives of the present study were to test a method for determining the critical level of dissolved CO_2 for bloater damage in brined cucumbers and to study variables, during the fermentation, that might affect response of the tissue to CO_2.

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MATERIALS & METHODS

SIZE NO. 3 pickling cucumbers (3.8–5.1 cm diam) were obtained from a nearby pickle company. Only cucumbers that were visibly free of disease and mechanical injury and normal in shape were brined.

The cucumbers were brined at a pack-out ratio of ca 50/50, w/v, cucumbers/brine, equaling ca 13 cucumbers, in 1-gal jars (3.8L), fitted with 250-ml expansion reservoirs as described earlier (Fleming et al., 1973a). The controlled fermentation procedure of Etchells et al., 1973, was used. This included brining to equalize at 6.9% NaCl, w/v, initial acidification of the cover brine with 6 ml of glacial acetic acid per gallon of brined cucumbers, addition of 0.5%, w/v, sodium acetate after 18–24 hr or after the initial cover brine was below 28° salometer (7.8% NaCl w/v) and inoculation with a culture of *Lactobacillus plantarum* WSO. The culture for inoculation was grown in cucumber juice broth (Fleming and Etchells, 1967) plus 5% NaCl for ca 16 hr at 30°C; ca 1×10^8 cells were added per gallon of brined material. Deviations from the above brining procedure are given in footnotes to tables for specific experiments.

Concentrations of dissolved CO_2 in brines were varied by bubbling mixtures of CO_2 and N_2, in varying proportions, through the brines. Specified mixtures of CO_2 and N_2 were obtained in pressurized cylinders (Air Products Company, Allentown, PA). The gas was introduced into the brine through fritted glass, gas dispersion tubes placed in the jars (Fleming et al., 1973a).

Dissolved CO_2 was analyzed according to Fleming et al. (1974). Expansion volume, %, which is the rise in the brine level as a consequence of gas accumulation inside the cucumbers expressed as percent of the original volume of the cucumbers, was determined by use of graduated expansion reservoirs attached through the jar caps (Fleming et al., 1973a). NaCl was determined by titration (Etchells et al., 1964).

Cucumber brine stock was evaluated for bloater damage by classifying according to type (balloon, lens, honeycomb) and degree (slight, moderate, advanced) as illustrated earlier (Etchells et al., 1974). The data were transformed into bloater index values according to Fleming et al. (1977) for statistical purposes: The bloater index is calculated from the numerical percentage of cucumbers affected and the degree of damage for balloon-, lens- and honeycomb-type bloaters. Weighted damage values (WDV) were assigned to adjectival ratings of the 10 degrees of damage given previously (Fleming et al., 1977). The index for balloon bloater damage, for example, was calculated as:

$$\text{Balloon index} = \frac{\text{\% affected by balloon damage} \times \text{WDV for balloon type}}{100}$$

Indexes for lens and honeycomb bloating were calculated similarly, and the overall bloater index was the sum of the three indexes:

$$\text{Bloater index} = \text{balloon index} + \text{lens index} + \text{honeycomb index.}$$

RESULTS

Carbonation of cucumber brines

Dissolved CO_2 in fermented cucumber brines varied linearly with the proportion of CO_2 in the carbonating gas mixture, at equilibrium (Fig. 1). Equilibrium concentrations of CO_2 in the brine at 19°C were greater than at 27°C as expected, since the solubility is greater at lower temperatures (Harned and Davis, 1943). The solubility of CO_2 at the two temperatures was nearly identical, however, when expressed as % saturation (Fig. 1).

Stages in susceptibility of cucumbers to bloater damage by artificial carbonation of the brines

Cucumbers varied in susceptibility to bloater damage according to the time after brining at which artificial carbonation was begun (Fig. 2). There were three distinct stages of susceptibility to bloater damage. Cucumbers bloated only slightly when carbonation of the brines with 100% CO_2 was begun immediately after brining (Stage I). No appreciable damage occurred on continuing the carbonation for several days (Fig. 3).

The cucumbers were highly susceptible to damage when carbonated between 1 and 32 days after brining (Stage II, Fig. 2). Response to carbonation at this stage was rapid, the expansion volume maximizing within 2 days (Fig. 3). At 49 days after brining, the cucumbers no longer responded to artificial carbonation (Stage III, Fig. 2), although the brines were saturated with CO_2.

Factors affecting bloater damage of brined cucumbers during Stages I and II

Heating cucumbers to 74°C, internal, did not prevent bloater formation by artificial carbonation (Experiment I, Table 1). Thus, it seems unlikely that enzymatic activity from

Table 1—Effect of heating fresh cucumbers on their susceptibility to bloat in brine upon artificial carbonation

Heat treatment of cucumbers	Time CO_2 started, days after brining	Max exp vol (%)	Bloater index			
			Balloon	Lens	Honeycomb	Total[d]
Experiment I (fermented)[a]						
Heated[b]	0	9.0	34	3	0	37 bc
	1	8.6	35	6	0	41 bcd
	7	11.5	43	3	0	46 cde
Not heated	0	8.9	6	1	2	9 a
	1	14.6	51	1	8	60 e
	7	15.7	31	0	24	55 de
Experiment II (not fermented)[c]						
Heated[b]	4	9.7	25	6	0	31 b
Not heated	4	15.0	60	0	0	60 e

[a] Size no. 3 cucumbers were packed, 60/40, cucumbers/brine, in 5-gal pails. A cover brine and dry salt were added to equalize at 6.9% NaCl, w/v, according to Etchells et al. (1973) for the controlled fermentation process. At the times indicated, the cucumbers were repacked into duplicate 1-gal jars, pack-out ratio 50/50, with expansion reservoirs, and carbonated by bubbling CO_2 through the solutions to saturation. Values are averages for duplicate jars.

[b] Cucumbers were heated in a water bath to an internal temperature of 74°C, held 5 min, then cooled in water prior to brining.

[c] These cucumbers were packed into 1-gal jars, 50/50 pack-out, and covered with a solution of 6.9% NaCl, w/v, 0.5% acetic acid, 0.5% lactic acid and 0.2% sodium benzoate. Additional salt was added in two increments of ca 24 hr each to equalize at 6.9%. No fermentation occurred in these jars during the period of study.

[d] Mean values in the column with a common letter are not significantly different (P > 0.05), according to Duncan's new multiple range test (Steel and Torrie, 1960).

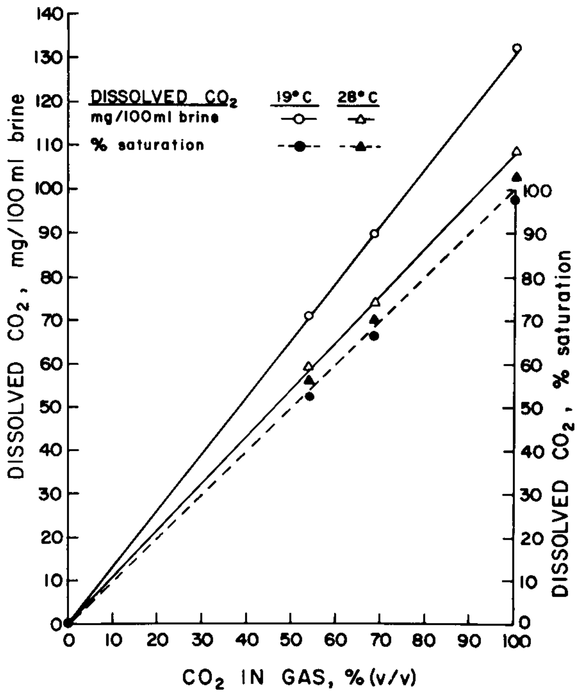

Fig. 1—Dissolved CO_2 in cucumber brines at equilibrium after carbonating with mixtures of CO_2 in N_2. NaCl, 5.5%.

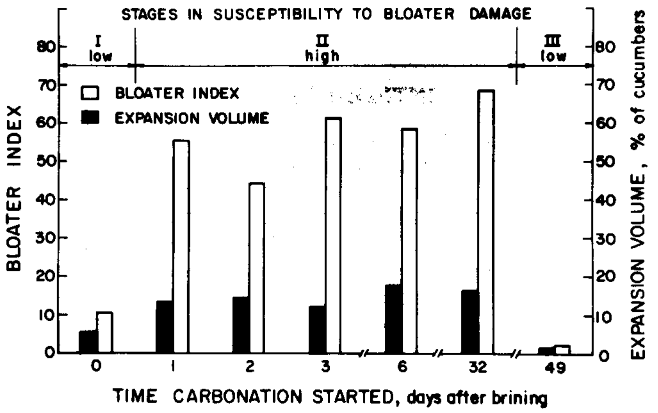

Fig. 2—Stages in the susceptibility of brined cucumbers to bloater damage by carbonation.

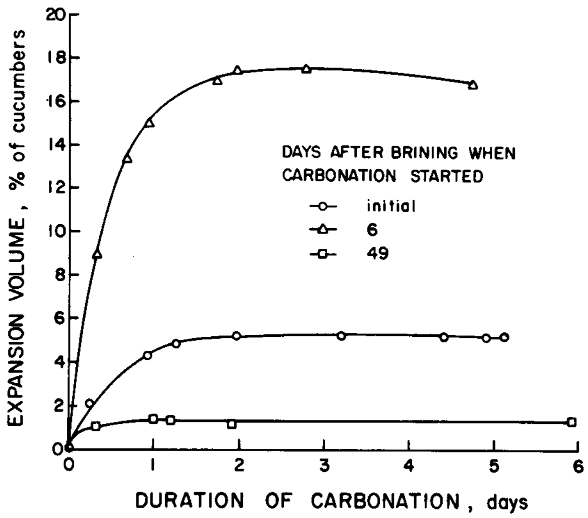

Fig. 3—Rate of bloater formation in cucumbers by carbonation at various stages after brining.

the cucumber tissue is necessary for bloater formation. In fact, heated cucumbers bloated to a considerable extent during the first day of brining, whereas unheated cucumbers did not (Table 1). When carbonation was begun beyond day 1 of brine storage, the unheated and heated cucumbers bloated to similar extents. The fact that carbonation of unheated cucumbers immediately after brining actually inhibited bloater formation is important. These cucumbers did not bloat upon extended carbonation (Fig. 3).

Fermentation by lactic acid bacteria was not essential for bloater formation of cucumbers by artificial carbonation (Experiment II, Table 1). Heated and unheated cucumbers bloated upon artificial carbonation, even though microbial fermentation was restricted by use of a preservative cover brine.

Bloater damage occurred in salt brines varying from 0–11.4%, whether or not the cucumbers fermented (Table 2). Analysis of variance indicated that bloater index increased significantly with salt concentration ($P < 0.01$), but differences in bloater index between fermented and nonfermented cucumbers were not significant ($P > 0.05$).

Conditions for bloater damage of Stage III cucumbers

Several experiments revealed that cucumbers held in brine for extended periods lost their susceptibility to bloater formation by artificial carbonation. In these experiments CO_2 never exceeded saturation, due to the method of carbonation.

Re-fermentation of stored brine stock by yeasts resulted in bloater formation when brines were not purged with nitrogen; nitrogen purging prevented bloater damage (Table 3). In all instances where bloater damage occurred, dissolved CO_2 exceeded saturation (supersaturation). *Lactobacillus brevis* fermentation also resulted in bloater formation, again apparently due to supersaturation of the brines (Table 3).

Although the stored brine-stock cucumbers did not bloat upon artificial carbonation and holding at 24°C, bloater formation occurred rapidly when the jars were placed at 43°C and above subsequent to carbonation (Table 4). Diffusivity of the cucumbers' internal CO_2 was too low to permit diffusion of the gas from the flesh before bloater damage occurred.

Table 2—Effect of salt concentration on bloater formation by artificial carbonation

Fermentation treatment[a]	NaCl (%)	Max exp vol (%)	Bloater index
Fermented[b]	0	9.5	64
	2.7	11.3	70
	5.5	16.0	67
	11.4	23.3	87
Not fermented[c]	0	7.4	54
	2.7	8.1	57
	5.5	16.0	81
	11.4	25.3	96

[a] Size no. 3 cucumbers were packed into duplicate 1-gal jars, pack-out ratio 50/50, with expansion reservoirs. Carbonation was begun 4 days after brining.

[b] These cucumbers were brined and inoculated with L. plantarum WSO according to the controlled fermentation process (Etchells et al., 1973).

[c] The cover brine for these cucumbers was 6.9% NaCl, w/v, 0.5% acetic acid, 0.5% lactic acid, and 0.2% sodium benzoate. Additional salt was added in two increments of ca 24 hr each to equalize at 6.9%. These brines did not ferment.

Effect of brine CO_2 levels on bloater damage

Brined cucumbers purged with N_2, or up to 35% CO_2 in N_2, had negligible bloater damage (Table 5). Damage increased significantly ($P < 0.01$), however, with 54–100% CO_2 in the purging gas. Although this trend was apparent in the three experiments reported in Table 5, extent of damage differed significantly among experiments ($P < 0.01$). Damage was greater in fermentations at 29°C than at 19°C ($P < 0.01$), although the CO_2 saturation in the brines was similar. Bloater damage was greater in nonpurged than in purged fermentations with corresponding CO_2 saturation ($P < 0.05$). Statistical analyses of the bloater damage for data in Table 5 followed that of a split-plot design with the temperature factor in the whole plots and the CO_2 levels in the subplots. Necessary adjustments were made for unequal numbers of replications in the temperature and CO_2 treatments.

Estimates of bloater damage (% expansion volume, bloater index, % bloaters) were more closely correlated with CO_2 saturation than with CO_2 concentration (Table 6). Expansion volume, an objective measurement, increased exponentially with CO_2 saturation, up to 100% saturation. The regression of Log [1 + % expansion volume] with CO_2 saturation appeared to be linear up to 100% CO_2 saturation (Fig. 4). The bloater index increased nearly linearly with expansion volume (Fig. 5), $r^2 = 0.83$. We have noted that up to about 3% expansion volume may occur without any noticeable bloater damage (departure from linearity). We interpret this volume of liquid displacement inside the cucumbers as representing the "elasticity" of the tissue to internal gas pressure (Fig. 5). Unless the elasticity of the tissue is exceeded, the tissue is not appreciably damaged insofar as visual appraisal is concerned. The elastic region varied among samples of cucumbers (Fig. 5).

DISCUSSION

BLOATER FORMATION in brined cucumbers may occur by a physical-chemical mechanism, based on the level of brine CO_2 and the rate of CO_2 diffusion through the cucumber tissues. Bloater damage was induced by artificial carbonation of heat-inactivated cucumbers in the absence of microbial

Table 3—Susceptibility of stored brine-stock cucumbers to bloater damage by yeasts and gas-forming lactic acid bacteria[a]

Microorganism used for refermentation	Purging treatment	Dissolved CO_2 mg/100 ml	Dissolved CO_2 % saturation	Bloater index Balloon	Bloater index Lens	Bloater index Honeycomb	Bloater index Total
None (original brine stock)	None	–	–	2	2	1	5
None (original brine stock)	100% CO_2	105	100	0	2	4	6
Saccharomyces rosei	None	165	132	82	0	2	84
Saccharomyces rosei	N_2	1	1	2	0	11	13
Hansenula subpelliculosa	None	166	133	65	0	0	65
Saccharomyces cerevisiae	None	138	110	85	0	0	85
Lactobacillus brevis	None	118	110	72	10	0	82

[a] Commercial salt stock cucumbers, size no. 3, having been stored in brine for several months and nearly bloater free, were packed in 1-gal jars, 60/40 pack-out ratio, cucumbers/brine, and covered with a spent brine to equalize at ca 3% NaCl (pH 3.8, 0.28% acid). The brine was fortified with 3% glucose, 0.5% Bactopeptone (Difco), and 0.5% yeast extract. For L. brevis fermentations, 0.5% sodium acetate was added to the brine and adjusted to pH 4.5 with acetic acid. The jars were incubated at 26°C.

growth. Inhibition of bloater formation in unheated cucumbers by continuous carbonation immediately after the brining (Fig. 2) suggests, however, that biological factors may also control bloater formation during the early stages of brining. Also, published data showed that removal of CO_2 from the brine of natural fermentations did not consistently reduce bloater formation (Fleming et al., 1975). It was suggested that the initial acidity and resultant low pH of the cover brine of controlled fermentations made the cucumbers more responsive to the purging treatment. The natural fermentations of Fleming et al. (1975) were not acidified, but brines were acidified in the present studies.

Present and former (Fleming et al., 1973a) studies revealed that bloater formation may occur at subsaturation levels of CO_2 in the brine. The mechanism of bloater formation by physical-chemical means at subsaturation levels of CO_2 may be explained thusly: dissolved CO_2 inside the cucumber attains equilibrium with micro or macro gas pockets within the cu-

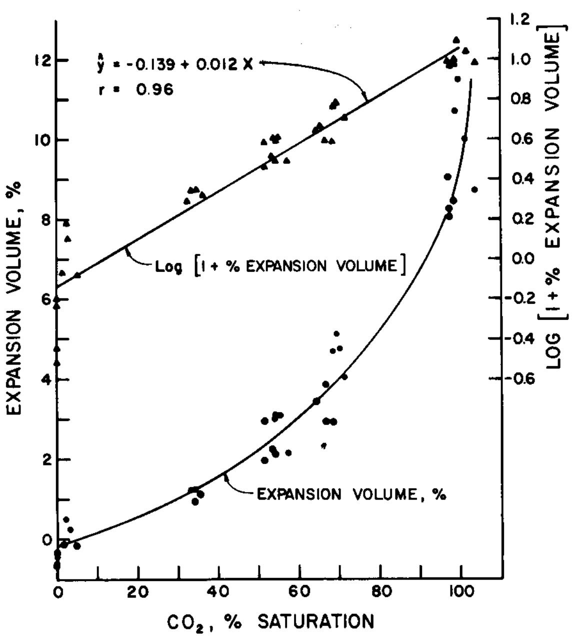

Fig. 4—Relationship between CO_2 saturation and expansion volume of brined cucumbers.

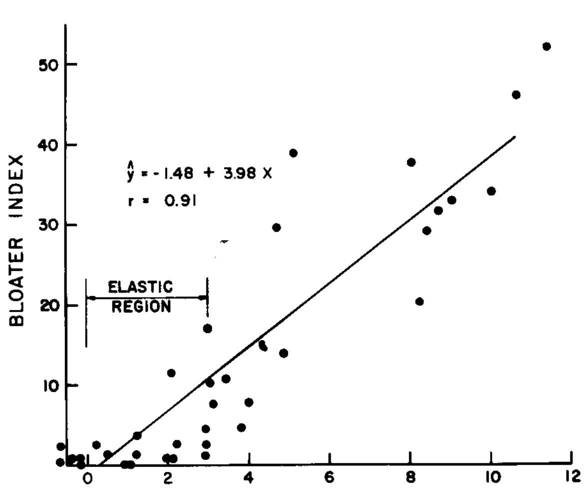

Fig. 5—Relationship between expansion volume and bloater index of brined cucumbers.

Table 4—Susceptibility of stored brine-stock cucumbers to bloater damage by heating the carbonated stock[a]

Heating temp (°C)	Max exp vol % of Cucumbers (hr)	Bloater index		
		Balloon	Lens	Total
24	0	2	2	5
43	17.8 (30)[b]	52	10	67
54	20.0 (30)	85	0	85
66	24.7 (2)	85	0	85
77	27.5 (1)	85	0	85

[a] Commercial salt stock cucumbers, size no. 3, nearly bloater free, were packed in 1-gal jars, 60/40 pack-out ratio, cucumbers/brine, covered with a 24°C brine to equalize at 5% NaCl. This brine was carbonated to near saturation (ca 108 mg CO_2/100 ml brine at 24°C) and the jars then placed at the temperatures indicated.
[b] Hours required for attainment of maximum expansion volume.

Table 5—Effect of CO_2 level on bloater damage in brined, fresh cucumbers[a]

	19°C			29°C		
CO_2 in purging gas[b] (%)	Dissolved CO_2 % sat	Bloater index Balloon	Bloater index Total	Dissolved CO_2 % sat	Bloater index[c] Balloon	Bloater index[c] Total
Experiment I						
0	(Not determined)			5	0.0	0.0
12				17	0.0	0.4
35				38	0.0	1.4
47				48	1.2	3.8
60				66	2.5	6.1
76				78	1.3	7.3
100				99	4.0	20.7
Not purged				70	1.8	25.8
Experiment II						
0	3	0.0	0.4	3	0.0	1.9
33	35	0.0	0.0	34	0.8	2.5
54	54	0.0	1.8	54	4.5	9.0
69	67	0.9	3.6	70	12.6	34.2
100	97	20.0	35.5	99	22.9	49.1
Not purged	44	5.4	11.5	69	4.2	52.8
Experiment III						
0	0	0.0	0.6	0	0.8	1.4
54	52	0.0	1.0	56	11.9	14.3
68	66	6.1	7.6	70	6.5	10.9
100	98	20.9	24.8	103	23.7	32.8
Not purged	52	7.1	25.3	71	3.4	51.6

[a] Size no. 3 cucumbers were packed into duplicate 1-gal jars, pack-out ratio 50/50, with expansion reservoirs. The brines were inoculated with L. plantarum WSO according to the controlled fermentation process (Etchells et al., 1973).
[b] Purging gases were begun after 2 days' brine storage for Experiment I and after 7 days' storage for Experiments II and III. Duplicate jars in each experiment were not purged.
[c] Differences between balloon and total bloater indexes are due to lens and honeycomb indexes.

Table 6—Correlation coefficients among variables related to bloater damage[a]

Variable	% Expansion volume	Bloater index	% Bloaters
CO_2 concentration	0.87	0.68	0.72
CO_2 % saturation	0.92	0.77	0.82
Expansion vol, (%)	–	0.91	0.85
Bloater index	–	–	0.84

[a] Correlation coefficients based on experiments reported in Table 5.

cumber tissue, according to Henry's law. As the concentration of dissolved CO_2 increases, the concentration of CO_2 in the gas pocket increases. This results in increased pressure in the gas pocket and consequently an increased volume, depending on resistance of the tissue to the gas pressure. This mechanism is similar to that proposed by Etchells et al. (1968), except that we now know that brine of freshly brined cucumbers does not have to be supersaturated with CO_2 as stipulated by Etchells et al. (1968), for bloater damage to occur. Supersaturation may be necessary, however, for bloater damage in stored brine-stock cucumbers.

Present knowledge is insufficient to specify a precise critical level of dissolved CO_2 for bloater damage. Bloater damage was more closely correlated with % saturation than with concentration of CO_2. Even so, the critical % saturation varied due to differences in temperature, salt concentration and the cucumbers. Also, nonpurged cucumbers bloated to a greater extent than artificially carbonated cucumbers, even at similar levels of CO_2 (Table 5). This phenomenon may be due to the relative quiescence in the noncarbonated as compared to the carbonated cucumbers. Hydrostatic and buoyancy pressures also influence bloater damage (Fleming et al., 1977). Previous work demonstrated that large cucumbers bloat more readily than small ones, at similar levels of CO_2 (Fleming et al., 1973a). Herein, however, we found important variations among cucumbers of the same size. This observation has been made with cucumbers of unknown, as represented herein, and with known cultivars. For these reasons, we suggest that cultivar, season and post-harvest storage conditions of cucumbers and other factors may contribute to the critical level of CO_2 for bloater damage. The method of artificial carbonation described herein standardizes the level of CO_2, and may be useful in studying variables of the cucumbers that contribute to their susceptibility to bloater damage.

In purging CO_2 from the brine to prevent bloater formation on a commercial scale, some compromise must be made between level of CO_2 and expense of the nitrogen purging gas. In present studies, serious bloater damage was avoided when brine CO_2 did not exceed 50% saturation. Some bloater damage may occur near the top of commercial brining tanks at this level of CO_2 saturation, but the damage would probably not be important beyond a depth of 2 to 3 ft because of effects of hydrostatic pressure (Fleming et al., 1977).

Fermentable sugars may remain in cucumber brines after fermentation by lactic acid bacteria and be fermented by yeasts unless the brine is buffered as in the controlled fermentation process of Etchells et al. (1973). Fortunately, cucumbers become less susceptible to bloater damage by subsaturation levels of CO_2 during extended brine storage. However, the presence of fermentable sugars and inevitable yeast fermentation can yield brines that are supersaturated with CO_2, and thus cause serious bloater damage.

Bloater damage also can occur after removal of salt stock from the brining tanks during subsequent desalting operations in which heat may be used to speed salt diffusion or to produce a cured appearance in partially white, opaque flesh. It would be advantageous to purge high levels of CO_2 from brines before unloading the tanks for processing.

REFERENCES

Costilow, R.N., Bedford, C.L., Mingus, D. and Black, D. 1977. Purging of natural salt stock pickle fermentations to reduce bloater damage. J. Food Sci. 42: 234.

Etchells, J.L. and Bell, T.A. 1950. Classification of yeasts from the fermentation of commercially brined cucumbers. Farlowia 4: 87.

Etchells, J.L., Bell, T.A., Fleming, H.P., Kelling, R.E. and Thompson, R.L. 1973. Suggested procedure for the controlled fermentation of commercially brined pickling cucumbers—The use of starter cultures and reduction of carbon dioxide accumulation. Pickle Pak Sci. 3: 4.

Etchells, J.L., Bell, T.A., Fleming, H.P., Kelling, R.E. and Thompson, R.L. 1974. Bloater chart. Published and distributed by Pickle Packers International, Inc., St. Charles, IL.

Etchells, J.L., Borg, A.F. and Bell, T.A. 1968. Bloater formation by gas-forming lactic acid bacteria in cucumber fermentations. Appl. Microbiol. 16: 1029.

Etchells, J.L., Costilow, R.N., Anderson, T.E. and Bell, T.A. 1964. Pure culture fermentation of brined cucumbers. Appl. Microbiol. 12: 523.

Etchells, J.L., Fabian, F.W. and Jones, I.D. 1945. The Aerobacter fermentation of cucumbers during salting. Mich. Agr. Expt. Sta. Tech. Bull. No. 200, 56 pp.

Etchells, J.L., Fleming, H.P., Hontz, L.H., Bell, T.A. and Monroe, R.J. 1975. Factors influencing bloater formation in brined cucumbers during controlled fermentation. J. Food Sci. 40: 569.

Fleming, H.P. and Etchells, J.L. 1967. Occurrence of an inhibitor of lactic acid bacteria in green olives. Appl. Microbiol. 15: 1178.

Fleming, H.P., Etchells, J.L., Thompson, R.L. and Bell, T.A. 1975. Purging CO_2 from cucumber brines to reduce bloater damage. J. Food Sci. 40: 1304.

Fleming, H.P., Thompson, R.L., Bell, T.A. and Monroe, R.J. 1977. Effect of brine depth on physical properties of brine-stock cucumbers. J. Food Sci. 42: 1464.

Fleming, H.P., Thompson, R.L. and Etchells, J.L. 1974. Determination of CO_2 in cucumber brines. AOAC 57: 130.

Fleming, H.P., Thompson, R.L., Etchells, J.L., Kelling, R.E. and Bell, T.A. 1973a. Bloater formation in brined cucumbers fermented by Lactobacillus plantarum. J. Food Sci. 38: 499.

Fleming, H.P., Thompson, R.L., Etchells, J.L., Kelling, R.E. and Bell, T.A. 1973b. Carbon dioxide production in the fermentation of brined cucumbers. J. Food Sci. 38: 504.

Harned, H.S. and Davis, R. 1943. The ionization constant of carbonic acid in water and the solubility of CO_2 in water and aqueous salt solutions from 0 to 50°. J. Am. Chem. Soc. 65: 2030.

Marshall, D.E., Levin, J.H. and Heldman, D.R. 1973. Density sorting of green stock cucumbers for brine stock quality. ASAE paper 73–304.

Samish, F., Dimant, D. and Marani, T. 1957. Hollowness in cucumber pickles. Food Manuf. 32: 501.

Steel, R.G.D. and Torrie, J.H. 1960. "Principles and Procedures of Statistics." McGraw-Hill Book Co., Inc., New York, NY.

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