MECHANISM FOR BLOATER FORMATION IN BRINED CUCUMBERS

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ABSTRACT

The susceptibility of pickling cucumbers to bloat damage during storage in CO₂-charged brine depended upon the internal gas composition of the cucumbers before brining. Gas extracted from fresh cucumbers consisted of about 75% N₂, 20% O₂, and 6.0% CO₂. Replacement of that gas with CO₂ or O₂ reduced the susceptibility of the fruit to bloatter damage upon subsequent storage in carbonated brine. Bloatter damage was related directly to % N₂ and inversely to % CO₂ in the internal gas of the cucumbers when they were brined. These and other findings are the basis of the following mechanism we propose to explain bloatter formation of cucumbers in brine containing CO₂. When cucumbers are brined, liquid clogs the intercellular gas spaces of the tissues that normally permit rapid diffusion of gases in fresh cucumbers. The liquid-clogged layer encloses the internal gases within the fruit and functions as a differentially permeable barrier to N₂ and CO₂. Since N₂ is the predominant gas within the fresh fruit, and since CO₂ concentration in the brine is high, a diffusion gradient for CO₂ exists toward the fruit interior. CO₂, which is much more water soluble than N₂, diffuses from the brine into the fruit faster than N₂ can diffuse from the fruit. Ultimately, the transfer of CO₂ to the fruit interior results in insufficient internal gas pressure due to CO₂ plus N₂ to rupture the flesh, causing a gas pocket (bloatter formation).

INTRODUCTION

PURGING of CO₂ from the brine of fermenting cucumbers with N₂ or air has been shown to greatly reduce bloatter damage in the brine-stock cucumbers (Etchells et al., 1973; Fleming et al., 1973, 1975; Costilow et al., 1977). Many pickle companies now purge their brines to reduce losses. Although N₂ has been generally recommended as the purging gas, some briners are either experimenting with or are using air because of its relatively low cost. The use of air presents possible problems with softening, off colors and flavors, and lowering of brine acidity (Fleming et al., 1975; Potts and Fleming, 1979).

Economically, it would be desirable to minimize the amount of N₂ required for purging. For this reason, Fleming et al. (1978) tested the susceptibility of cucumbers to various levels of CO₂ in the brine in order to establish a critical level of CO₂ for bloatter damage. Concentration of CO₂ in the brine was controlled by bubbling various mixtures of CO₂ in N₂ through the cucumber brines. Bloatter damage resulted from this artificial means of carbonation in heated and unheated cucumbers and in fermented and unfermented cucumbers. They concluded, therefore, that bloatter damage can occur by a physicochemical mechanism, independent of metabolism and CO₂ production from microbial action or cucumber tissue. Etchells et al. (1968) earlier suggested a physicochemical mechanism for bloatter damage, and indicated that supersaturated levels of CO₂ were needed for bloatter formation to occur. Fleming et al. (1978) showed, however, that bloatter damage can occur at subsaturated levels of CO₂ in the brine. The critical level of CO₂ for bloatter damage depended on numerous variables, including brine temperature, salt concentration, and the time when CO₂ was added to the brine.

If carbonation was begun immediately after brining, the cucumbers did not bloat extensively, even after extended carbonation. Bloatter damage was extensive, however, if carbonation was begun about 1 day after brining. About a month or longer in brine storage, the cucumbers were no longer susceptible to bloatter damage by artificial carbonation, even when the brine was saturated with CO₂. These cucumbers did bloat, however, if subjected to supersaturated levels of CO₂ due to yeast fermentation.

The objective of our study was to gather sufficient data on the gas composition and rates of gas exchange of fresh and brined cucumbers so that we might develop a working hypothesis for the mechanism of bloatter formation due to carbonation of brined cucumbers. Specifically, we: (a) determined rates of exchange of N₂, CO₂, and O₂ in fresh and brined cucumbers, and (b) studied the relation between internal gas composition of cucumbers before brining and bloatter damage of the cucumbers in artificially carbonated brine.

MATERIALS & METHODS

Cucumbers

Size no. 3 pickling cucumbers (3.8–5.1 cm diam) were obtained from nearby pickle companies. Only fruit free of obvious physical damage and disease were used. Brined cucumbers were evaluated for bloatter damage according to Etchells et al. (1974), and bloatter indexes were calculated according to Fleming et al. (1977).

Gas exchange of fresh cucumbers

Cucumbers (1.9 kg) were packed into 3.8-liter (1-gal) glass jars. Each jar was then sealed with a screw-on cap fitted with a 250-ml expansion reservoir calibrated to measure brine expansion volume during broter formation (Fleming et al., 1973). The jar cap also contained portholes through which were inserted a glass gas dispersion tube and a 0.8 cm diam glass rod to support the reservoir (Fig. 1). Air, CO₂, O₂, or N₂ was introduced through a flowmeter into the jar of cucumbers.

Brining

After gas exchange treatment, brine was poured through the reservoir and into the jar. During brine addition, the gas flow was allowed to continue so that air was excluded from the jar. The brine contained 9.8% (w/v) NaCl, 0.32% (v/v) glacial acetic acid, and 0.2% sodium benzoate. When the jar was filled, the gas flow was discontinued, and brine added to the 50 ml mark in the reservoir. Brines were artificially carbonated by bubbling pure CO₂ (50 ml/min) through the brines, as described earlier (Fleming et al., 1978). Expansion volume of the brined cucumbers was determined from the rise in brine level in the reservoir (Fleming et al., 1973) and was expressed as percent of the volume of cucumbers in the jar. Expansion volume is directly related to bloatter formation (Fleming et al., 1973; 1978).

Gas extraction and analysis

Fruit were immersed in a 2M MgSO₄ solution which had been adjusted to pH 2.5 with HCl and which was contained in an inverted bell jar. An inverted, plastic funnel was placed over the fruit within the bell jar and pushed into the solution until all gas was displaced from the funnel; then, the funnel was sealed with a rubber serum cap. A vacuum desiccator lid connected to a vacuum pump was then placed on the bell jar, and the system was subjected to a vacuum of 0.1 atmosphere for about 15 sec. Gases in the interior of the fruit

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expanded, escaped from the fruit surface as streaming bubbles, and were collected in the funnel. For fruit which had been under brine for several days, it was necessary to puncture their surface with a hypodermic needle immediately prior to gas extraction, otherwise they exploded at the low pressure. After return to atmospheric pressure, a 0.5-cc sample of the gas was removed with a syringe through the rubber serum cap and its composition analyzed with a Hamilton-Fisher Gas Partitioner, model no. 29. Gas analyses are reported as percentage composition by volume of the extracted gas sample, using pure O₂, N₂, or CO₂ as calibration standards. Failure of composition to total 100% represents analytical variations. The high aqueous solubility of CO₂ can present serious problems in such a procedure. However, we found that by using acidified MgSO₄, according to Jorge (1978), the composition of the headspace gas was highly stable.

Rubber balloon model

Gas-filled balloons were used to demonstrate principles involved in bloater formation. An apparatus identical to that shown in Figure 1 was used, except that the cucumbers were replaced by a submerged, deflated balloon attached through its opening to a capillary tube fitted to a rubber serum stopper in the jar lid (balloons were inflated and deflated several times to increase their elasticity prior to use in the experiments). Jars were filled with water and carbonated overnight to saturate the water with CO₂. Gas mixtures of 200 ml volume at room temperature were introduced by syringe into the balloons through the serum stoppers and capillary tube to initiate the experiment. The initial gases placed inside the balloons within three jars were 100% N₂, 100% CO₂, and a 1:1 (v/v) mixture of CO₂ and N₂. Expansion of the balloons was determined from the rise in the water in the expansion reservoir upon continued carbonation of the water within the jars at 50 ml of CO₂/min.

Exchange rates of fresh versus brined cucumbers

The rates at which N₂ and CO₂ would exchange in fresh cucumbers and in cucumbers that had been brined for 3 days were measured. Fresh cucumbers were placed in a series of jars, and the jars were then flushed with CO₂ at a flow rate of 500 ml/min for 1 hr so that their internal atmosphere was 100% CO₂. One-half of these jars were filled with CO₂-saturated brine and CO₂ was bubbled through the brine at 50 ml/min/CO₂ for 3 days. The remaining jars were filled with carbonated brine to wet the surfaces of the fresh fruit and the brine was immediately removed in a manner such that CO₂ continued to flow into the jar during this surface wetting procedure. These wetted, fresh fruit were then exposed within the jars to pure N₂, at a flow rate of 50 ml/min. Immediately prior to introduction of N₂ into the jar and after 15, 30, 45, and 60 min of N₂ exposure, the internal gas of the cucumbers was extracted and analyzed as described above. The fruit brined for 3 days were drained and the procedure described above for introducing N₂ into the jars and periodically analyzing the internal atmospheres of the fruit was carried out.

RESULTS

Gas exchange in fresh cucumbers

The natural internal atmospheres of four separate harvests of fresh pickling cucumbers averaged 5.7% CO₂ (SD 2.8%), 20.5% O₂ (SD 1.3%), and 75.2% N₂ (SD 1.5%). These values are consistent with findings of Jorge (1978).

When cucumbers were exposed to a CO₂ atmosphere, their internal gas composition changed from ca 2% CO₂ to over 90% within 1 hr, at a CO₂ flow rate of 50 ml/min (Fig. 2). Cucumbers treated in this manner are hereinafter referred to as “CO₂-exchanged.” The percentages of N₂ and O₂ in the fruit interior decreased correspondingly. Changes in internal gas composition were even more rapid at a flow rate of 500 ml CO₂/min, being ca 90% complete within 0.5 hr. Thus, the internal gas of fresh pickling cucumbers apparently can exchange rapidly with the external atmosphere. When CO₂ was bubbled (50 ml/min for 5 hr) through freshly brined cucumbers, before the cucumbers became susceptible to bloater damage by brine carbonation, the internal gas composition of the fruit was 89% CO₂, 1% O₂, and 12% N₂. Thus, cucumbers also are capable of rapid gas exchange immediately after brining.

Bloating susceptibility of CO₂-exchanged cucumbers

The magnitude and rate of expansion volume changes in CO₂-exchanged cucumbers, which were subsequently brined and carbonated, varied inversely with the time the cucumbers had been exposed to a CO₂ atmosphere prior to brining (Fig. 3). The bloater index of CO₂-exchanged cucumbers was directly related to the % N₂ and inversely
related to the % CO₂ composition of the internal gas of the cucumbers prior to brining (Fig. 4). Bloater damage and the maximum % expansion volume were directly related, as has been shown previously (Fleming et al., 1978). Bloater damage consisted of balloon, lens, and honeycomb types (Table 1) and was typical of damage incurred in brine-fermented cucumbers.

Immediately after cucumbers were exchanged with CO₂ or O₂, their internal gas consisted mostly of the exchange gas (Table 2). Exchange of the internal gas of cucumbers with CO₂ or O₂ reduced bloater damage upon subsequent brining and carbonation (Table 2). Cucumbers without gas exchange served as controls, showing the effects of normal internal gas composition on bloater damage.

Effects of CO₂ and O₂ exchange gases on internal gas composition of cucumbers after a 2-day storage in brine were determined (Table 3) for comparison with internal composition immediately after gas exchange (Table 2). The internal gas of both CO₂- and O₂-exchanged cucumbers contained mostly CO₂ after the 2-day brine storage. The 5.1% O₂ in the O₂-exchanged and brined cucumbers (Table 3) contrasted greatly with the 86% O₂, which the fruit contained immediately after O₂ exchange (Table 2). Again, bloater damage was significantly lower in CO₂- or O₂-exchanged cucumbers than in cucumbers that were not exchanged with pure gases.

Particularly interesting in the O₂-exchanged cucumbers was the visual observation of complete cure (translucent as compared to white, opaque flesh in fresh cucumbers) when the fruit were cut and examined 2 days after brining (Fig.

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**Table 1—Bloating susceptibility of CO₂-exchanged cucumbers to carbonation when brined**

<table>
<thead>
<tr>
<th>CO₂-exchange treatmenta</th>
<th>Balloonb (%)</th>
<th>Lens (%)</th>
<th>Honeycomb (%)</th>
<th>Bloater index</th>
</tr>
</thead>
<tbody>
<tr>
<td>(min)</td>
<td>(flow, ml/min)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>50</td>
<td>35 SM</td>
<td>5 S</td>
<td>20.0</td>
</tr>
<tr>
<td>15</td>
<td>50</td>
<td>25 SA</td>
<td>15 SM</td>
<td>14.0</td>
</tr>
<tr>
<td>30</td>
<td>50</td>
<td>15 SM</td>
<td>10 SM</td>
<td>13.5</td>
</tr>
<tr>
<td>45</td>
<td>50</td>
<td>15 SM</td>
<td>10 S</td>
<td>11.5</td>
</tr>
<tr>
<td>60</td>
<td>500</td>
<td>10 S</td>
<td>0 S</td>
<td>2.0</td>
</tr>
</tbody>
</table>

a CO₂ was allowed to flow into 1-gal jars of cucumbers at the times and rates indicated before introducing the cover brine.

b Letters following numerals indicate the severity of bloater damage: S = slight; M = moderate; A = advanced. When two letters are shown, the first indicates the degree of damage in the majority of the cucumbers. See Etchells et al. (1974).

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**Table 2—Effects of exchange gas on internal gas composition of cucumbers prior to brining and on bloater damage upon subsequent carbonation of the brined cucumbers**

<table>
<thead>
<tr>
<th>Exchange gas</th>
<th>CO₂ (%)</th>
<th>O₂ (%)</th>
<th>N₂ (%)</th>
<th>Max expansion volume (%)</th>
<th>Bloater index</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>8.9</td>
<td>21.9</td>
<td>74.1</td>
<td>9.2</td>
<td>20.0</td>
</tr>
<tr>
<td>CO₂</td>
<td>101.5</td>
<td>0.9</td>
<td>2.4</td>
<td>4.5</td>
<td>3.0</td>
</tr>
<tr>
<td>O₂</td>
<td>5.0</td>
<td>86.4</td>
<td>4.0</td>
<td>3.2</td>
<td>6.2</td>
</tr>
<tr>
<td>L.S.D 0.05</td>
<td>1.6</td>
<td></td>
<td></td>
<td>9.2</td>
<td></td>
</tr>
</tbody>
</table>

Cucumbers exposed to exchange gas, 500 ml/min, for 1 hr before internal gas composition was analyzed.

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![Graph](image)  
**Fig. 3**—Expansion volume changes in CO₂-exchanged cucumbers upon brining and carbonation. Cucumbers contained gases of the indicated compositions prior to brining. See Table 1 and Fig. 4 for related data.

![Graph](image)  
**Fig. 4**—Effects of % N₂ and % CO₂ in the internal gas of fresh pickling cucumbers on bloater damage upon subsequent brining and carbonation.
5). This rapid visual cure did not result with the other treatments detailed in Table 3. Also, we noted that **O**₂-exchanged cucumbers absorbed brine rapidly immediately upon immersion in brine. Apparently, the brine filled the air spaces within the tissue, and thereby, resulted in the cured appearance.

**Comparison of rates at which N₂ exchanged with CO₂ in fresh and brined cucumbers**

A comparison of the rates of CO₂ removal from fresh and brined cucumbers was determined by exposing CO₂-exchanged fruit to a flow of N₂. CO₂ removal was more rapid from fresh than from brined cucumbers upon exposing the surface-dried cucumbers to N₂. Also, the internal % N₂ increased more rapidly in fresh than brined fruit (Fig. 6).

**Rubber balloon model for bloater formation**

Upon exposure of gas-filled balloons to carbonated water, the water steadily rose in the expansion reservoir a net total of 265 ml after 2 hr when the balloon initially contained 100% N₂, a net total of 128 ml when the balloon initially contained 1:1 (v/v) CO₂ and N₂, and 0 ml when the balloon initially contained only CO₂ (Fig. 7). We subsequently demonstrated that water displaced into the expansion reservoir was almost quantitatively related to measured volumes of air added to the balloons by a syringe through the rubber serum stoppers. Thus, hydrostatic pressure effects and physical resistance of the balloon to expansion were negligible in the apparatus.

Periodic analyses of the composition of gas contained within the balloons during the course of volume changes revealed a constantly increasing % CO₂ and decreasing % N₂ in both balloons which contained N₂ gas (data not shown). However, within the limits of experimental error, no appreciable net loss in N₂ from the balloons occurred during the 2-hr experiment, when volume changes were

<table>
<thead>
<tr>
<th>Exchange gas</th>
<th>N₂ purged after brining and before carbonation</th>
<th>Internal gas comp. (%)</th>
<th>Visual cure (%)</th>
<th>Blaster index (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>Yes b</td>
<td>2.1 3.7 93.3</td>
<td>20</td>
<td>13.9</td>
</tr>
<tr>
<td>None</td>
<td>No</td>
<td>49.7 4.8 47.5</td>
<td>20</td>
<td>17.8</td>
</tr>
<tr>
<td>CO₂ a</td>
<td>No</td>
<td>97.7 1.3 5.9</td>
<td>45</td>
<td>3.0</td>
</tr>
<tr>
<td>O₂ a</td>
<td>No</td>
<td>83.3 5.1 17.3</td>
<td>100</td>
<td>0.0</td>
</tr>
<tr>
<td>LSD 0.05</td>
<td>12.0 5.2 12.4</td>
<td></td>
<td>12.4</td>
<td></td>
</tr>
</tbody>
</table>

a Fresh cucumbers were exposed to a gas flow of 500 ml/min for 1 hr prior to addition of brine.
b Purged continuously with nitrogen at 50 ml/min after addition of brine.
c Determined 2 days after brining. See Figure 5 for visual appearance of the cut cucumbers.
d A duplicate lot of cucumbers was carbonated at 50 ml CO₂/min, starting 3 days after brining and continuing for 2 days for the purpose of determining bloating susceptibility of the variously treated cucumbers.

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**Fig. 6—Changes in the internal gas composition of fresh and brined cucumbers during N₂ purging.**
MECHANISM FOR BLOATER FORMATION...

Table 4—Properties of gases in water and in air

<table>
<thead>
<tr>
<th>Variable</th>
<th>CO₂</th>
<th>O₂</th>
<th>N₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diffusion coefficient</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>In air (cm²·S⁻¹)</td>
<td>0.139</td>
<td>0.178</td>
<td>...</td>
</tr>
<tr>
<td>In water (cm²·S⁻¹ X 10⁶)</td>
<td>1.71¹</td>
<td>1.98¹</td>
<td>2.02²³</td>
</tr>
<tr>
<td>Solubility in water</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>g/100g water, 27°C</td>
<td>0.1366</td>
<td>0.0038</td>
<td>0.0017</td>
</tr>
</tbody>
</table>

a From Hodgman et al. (1955).
b From International Critical Tables (1929).
c Superscript numbers indicate temperature (°C).
d Data not given.

Bloater damage occurred in artificially carbonated, brined cucumbers at 52 and 66% CO₂ saturation, e.g., depending on brine temperature (Fleming et al., 1978). The results of our study show that the internal gas composition of cucumbers at the time of brining can greatly influence their susceptibility to bloater damage upon brining.

Mechanism of bloater formation at subsaturation levels of CO₂

The following hypothesis may explain how bloater formation occurs when brined cucumbers are exposed to subsaturation levels of CO₂ in the surrounding brine. We propose that CO₂ diffuses into the brined fruit more rapidly than N₂ diffuses out, such that, eventually, gas pressure within the fruit exceeds the external pressure. Tissues then rupture, and pockets of gas accumulate (bloater formation) inside the fruit. Differential rates of gas diffusion in brined cucumbers are due to the formation of a continuous, liquid-clogged outer layer of tissue which is not present in fresh fruit, and the lower water solubility of N₂ than CO₂. Physical constants for gas diffusion and solubility (Table 4), and the following further evidence support this hypothesis.

The fleshy mesocarp of plant tissue contains intercellular air spaces (Esau, 1976). Fresh pickling cucumbers contain about 5–9%, by volume, of gases (Veldhuis et al., 1939; Jorge, 1978). These gases can rapidly exchange with the ambient gas atmosphere, as shown by our study and as illustrated in Figure 8A. The internal gas composition in Figure 8A is typical of that in fresh cucumbers, although we found the composition to vary. Air composition is that reported by Weast (1973).

Stomata are present in the cucumber epidermis (Smith et al., 1979) and may be an avenue through which gases pass. The rate of exchange between internal and external gases was much slower for brined than for fresh cucumbers (Fig. 6). We think that the intrusion of liquid into the skin and air spaces of the outer mesocarp tissue of brined cucumbers clogs the normal avenues for diffusion (Fig. 8B).

---Continued on next page---
Liquid intrusion into the tissue could occur soon after brining as a consequence of O₂ from the internal atmosphere of the cucumber being converted to CO₂ with a resultant drop in internal gas pressure due to dissolution of CO₂ in the tissue fluids as proposed by Fleming et al. (1980). Additional support for the formation of a liquid-clogged layer is the fact that brined fruit, not fresh fruit, exploded when exposed to 0.1 atmosphere in the gas extraction apparatus, unless the fruit surface was intentionally punctured prior to gas extraction. Increased resistance to gas diffusion in avocado fruit, as a consequence of fruit softening, has been attributed to liquid clogging of the air spaces by cell exudates (Ben-Yehoshua et al., 1963).

Liquid clogging of air spaces in outer mesocarp and skin tissue (Fig. 8B) would cause the enclosure of internal gases, which consist primarily of N₂ in nonexchanged cucumbers. We propose that in the brined cucumbers, the liquid layer functions as a differentially permeable barrier to CO₂ and N₂. The much greater water solubility of CO₂ than N₂ (Table 4) would allow a greater diffusion rate of CO₂ than N₂ through this aqueous barrier. Diffusion coefficients of these gases in water are not greatly different (Table 4). It is the difference in solubility of gases, therefore, that largely accounts for differences in relative diffusion rates in water for O₂, CO₂, and N₂ (1.0, 23.1, and 0.53, respectively; Krogh, 1919) and in body fluids (1.0, 20.3, and 0.53, respectively; Guntay, 1971).

Blower damage results, therefore, from the entrapment of N₂ inside of brined cucumbers by outer, liquid-clogged tissue and a subsequent increase in the internal, partial pressure of CO₂ (Fig. 8B). The CO₂ may originate within the tissue, or from carbonation of the brine surrounding the cucumbers. Ultimately, when the internal total gas pressure exceeds one atmosphere, the tissues give way, and gas pockets form (blotted areas). The onset of blower formation occurs when the internal pressure, due to CO₂ plus N₂, exceeds resistance by the tissue. The brine may contain a subsaturation level of CO₂, therefore, for blower formation. Oxygen-exchanged cucumbers did not blotti appreciably, apparently because O₂ was converted to CO₂ by tissue respiration as suggested by Fleming et al. (1980).

If cucumbers are carbonated immediately upon brining, blower damage is minimal, even with extended brine carbonation (Fleming et al., 1978). Apparently in this case, N₂ is displaced from the cucumbers by CO₂ before intercellular gas spaces become clogged and restrict the rate of N₂ removal from the tissue.

Blowing of brined cucumbers is analogous to the expansion of the rubber balloons, as shown in Figure 7. Rubber is over 10 times more permeable to CO₂ than the N₂ (International Critical Tables, 1929). CO₂ diffused from the surrounding carbonated liquid into the balloon in proportion to the CO₂ diffusion gradient. The rubber, therefore, acted like a differentially permeable membrane, as did the hydrated layer which forms in brined cucumbers.

Although microbial fermentation was excluded in all cucumber brining experiments reported herein, we believe that the above hypothesis for blower formation also applies when the source of CO₂ is from microbial growth.

Implications

The internal gas composition of pickling cucumbers before brining influences their bloating susceptibility during brine storage. Thus, factors which influence the gas composition of cucumbers prior to or during brining should be considered in relation to brining properties, especially in relation to blower damage. We and others have observed unexplained variations in bloater damage of pickling cucumbers. Physiological state of the fruit, as it influences gas composition, would be a prime factor for further study.

The possibility of intentionally altering the gas composition of fresh cucumbers prior to brining, in order to reduce susceptibility to bloater damage of the fruit during subsequent brining, has been explored (Fleming et al., 1980). That study showed that exchange of the internal gas with CO₂ or O₂ will greatly reduce susceptibility of the cucumbers to bloater damage by carbonation. The study also showed that the use of O₂ as the exchange gas offers unique possibilities because O₂-exchanged cucumbers took up brine much more rapidly, and thus, acquired a more rapid appearance of cure than cucumbers with a normal internal atmosphere.

REFERENCES


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