

# Developments in Cucumber Fermentation<sup>a</sup>

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Cucumbers may be used as a fermentation substrate by lactic acid bacteria in a solution of sodium chloride. Successful fermentation is dependent upon interactions among the microbiological, chemical and physical factors associated with suspension of a solid, porous vegetable in a liquid. Maintenance of structural integrity of the cucumbers is very important, and this introduces complexities not encountered in fermentation of liquid materials. This review summarises recent efforts to understand and control the critical factors associated with cucumber fermentations. New and emerging technologies that have evolved from fundamental studies included in the review are: reduction in sodium chloride concentration for brining; purging of CO<sub>2</sub> from fermenting brines to prevent gaseous deterioration of the cucumbers; gas exchange of fresh cucumbers to influence their brining properties; development of new and valuable cultures of lactic acid bacteria for use in fermentations, and development of an anaerobic tanking system for cucumber fermentations.

*Keywords:* Lactic acid bacteria; cucumbers; fermentation; sodium chloride; brine.

## 1. Introduction

Cucumbers constitute the largest volume of vegetables preserved by pickling in the United States. Approximately 550 000 metric tons of fresh cucumbers are grown on a total of 47 000 ha.<sup>1</sup> These cucumbers are processed into various flavoured whole or cut products that are consumed at the rate of 3.7 kg per capita year<sup>-1</sup>.<sup>2</sup>

The increasing popularity of cucumber pickles can be attributed largely to changes in processing methods. Brining in sodium chloride solution, with resultant lactic acid fermentation, is a centuries-old method of pickling cucumbers. Two newer methods of pickling introduced over the past few decades have resulted in milder acid-flavoured products with lower concentrations of sodium chloride. Firstly, pasteurisation, including direct acidification with vinegar or acetic acid, was introduced into the United States industry in the 1940s.<sup>3</sup> Secondly, refrigeration, including direct acidification and addition of sodium benzoate or other preservative, has become increasingly popular since the 1960s. Relative quantities of cucumbers currently preserved by the above three methods of pickling are: brine fermentation, 43%; pasteurisation, 43% and refrigeration, 14%.

Although pasteurised and refrigerated pickles have contributed to the growth in consumption of pickles in recent years, fermentation remains an important method of preservation for several reasons. Fermented pickles have a flavour and texture desired by many individuals. In addition, fermentation in bulk containers offers important economic advantages: (i) Large volumes of cucumbers can be preserved quickly during the hectic harvest season; (ii) the product can be removed from storage at various times during the year for manufacture into desired products,

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thus distributing labour and equipment needs throughout the year; (iii) bulk storage allows for market hedging; (iv) fermentation offers the potential for energy saving, since pasteurisation or refrigeration may not be required in properly fermented products. The remainder of this paper deals with fermented cucumbers held in bulk containers.

There are three general methods by which cucumbers may be fermented. Firstly, 'salt-stock' cucumbers are preserved by fermentation in 5 to 8% sodium chloride until all fermentable sugars are converted to acids and other end products. The salt concentration is then increased to 10 to 16% to ensure product stability in the open-faced tanks in which they are stored. The cucumbers are removed from storage during the year as required; they are desalted to the desired concentration of sodium chloride by leaching in water, and are then flavoured and packaged. The products may be packaged whole, cut, or combined with other pickled vegetables. The products may or may not be heated to ensure stability.

Secondly, 'genuine dill' pickles are fermented to completion in 4 to 5% sodium chloride. The product is flavoured by the addition of dill weed, garlic and other spices directly to the fermentation liquor. The cucumbers are not desalted, but are sold along with the fermentation liquor (filtered for clarification) in which they were held.

Thirdly, 'overnight dill' pickles are partially fermented in 2 to 4% sodium chloride containing dillweed and garlic. Fermentation is allowed to proceed until the desired acidity is attained and the product is then refrigerated. The cucumbers are fermented in small containers, typically 190 dm<sup>3</sup> barrels. The latter two products are specialty items and constitute a relatively small proportion of cucumbers preserved by fermentation.

## 2. Problems associated with fermented cucumbers

Unique problems are involved in the fermentation of whole vegetables in comparison with fermentation of liquids such as beer, wine, and milk. Structural integrity must be maintained in whole vegetables, which is not a factor with liquids. Bloater damage (Figure 1) is the result of gas accumulation inside the cucumber during brine fermentation.<sup>4</sup> Softening of the tissue is also a serious defect which may be caused by pectinolytic enzymes of either microbial (primarily fungal)

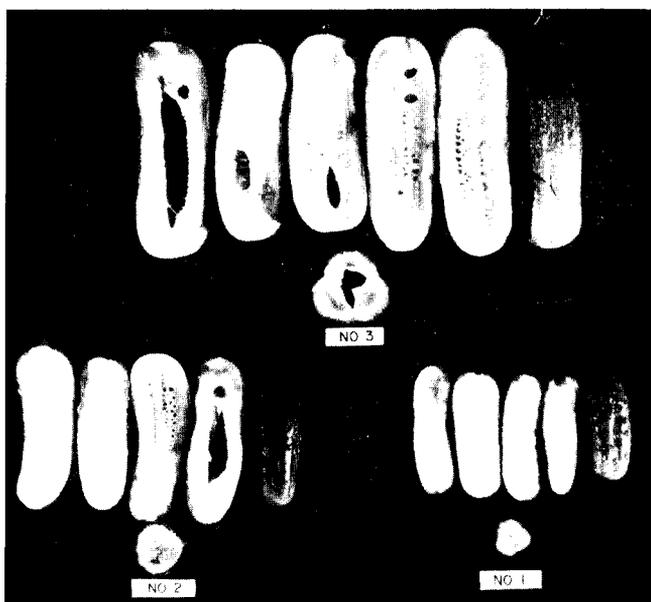


Figure 1. Bloater damage in fermented cucumbers. Damage is typically more severe in large (no. 3 size, 5.1–5.7 cm diameter) than in medium (no. 2, 3.8–5.1 cm) or small (no. 1, 2.7–3.8 cm) cucumbers.

origin,<sup>5</sup> or of the cucumber fruit itself.<sup>6</sup> Off-flavours and off-colours may result from improper fermentation and handling methods.

In addition to spoilage problems, the cucumber pickle industry is faced with disposal of wastes. These wastes consist of the salt used during fermentation and storage to prevent softening, and the organic wastes. Salt concentrations used greatly exceed the 2–3% desired in the final product. Thus, the excess salt must be leached from the cucumbers after brine storage, before they are processed into finished products. Disposal of this waste salt, which is not biodegradable, is a source of serious environmental concern.<sup>7</sup> As the salt is removed during leaching, the cucumber solubles also are removed, including desirable nutrients and flavour compounds. Not only are these desirable components lost, they must be degraded before discharge into waterways. Discharge of salt and organic materials into municipal disposal systems normally involves an additional expense to pickle companies since municipalities must charge to recover the cost of handling such wastes.

### 3. Critical factors in cucumber fermentations

Variables due to the cucumbers, environmental conditions under which they are held during fermentation, and the microorganisms that are naturally present or intentionally added, all influence the fermentation. Since maintenance of structural integrity of the cucumbers is so important, physical as well as chemical factors are involved. The interactions of these variables result in an extremely interesting and complex fermentation. Much research has been done on the fermentation of cucumbers and other whole fruits and vegetables. However, interactions of the microbiological, chemical, and physical factors involved are incompletely understood. Further understanding of these interactions is required before the cucumber fermentation industry can take full advantage of the biotechnology revolution that looms for many fermentation industries.

#### 3.1. Cucumbers

Maintenance of structural integrity of cucumbers during fermentation is greatly dependent on chemical and physical properties of the fresh fruit, including size, maturity, cultivar, and physiology. Diffusion of substrates from the cucumbers into the brine, and salt of the cover solution into the cucumbers is influenced by properties of the skin.<sup>8</sup> Likewise diffusion of gases is influenced by physical properties of the raw cucumbers.<sup>9</sup> Stomata in the skin of cucumbers (Figure 2) are thought to be the primary portals for entrance and exit of solutes and gases.<sup>10</sup> Stomatal density in the skin varies greatly with fruit size. The total number of stomata per fruit is constant; therefore the density decreases with increasing fruit size.<sup>10</sup>

Microbial fermentation is not limited to the cover brine, as was once thought.<sup>11</sup> Lactic acid bacteria have been shown to enter and proliferate within the brined cucumber,<sup>12</sup> confirming earlier evidence that bacteria occur within brined cucumbers.<sup>13</sup> Stomata are considered to be the route of entry of bacteria.<sup>12</sup> Most yeasts are thought to be unable to enter the fruit due to size limitation of the stomata.<sup>14</sup>

Sugar content and buffering capacity of cucumbers are important in determining the extent to which lactic acid bacteria can ferment before being inhibited by low pH. Cucumbers contain about 2% fermentable sugars, consisting essentially of glucose and fructose, and only traces of sucrose.<sup>15</sup>

Cucumbers, being fresh produce, are capable of various physiological responses when placed in brine solution during subsequent fermentation. Fresh cucumbers contain 5–7% by volume as intercellular gas space, the composition of which approximates 6% CO<sub>2</sub>, 20% O<sub>2</sub>, and 75% N<sub>2</sub>.<sup>4</sup> When brined, the cucumbers respire the entrapped O<sub>2</sub> with resultant CO<sub>2</sub> production. The CO<sub>2</sub> produced by the cucumber (that entrapped initially plus that formed while in brine) contributes to the total CO<sub>2</sub> present during fermentation.



Figure 2. Scanning electron micrograph of the surface of a pickling cucumber fruit showing two stomata and surrounding epidermal cell structure. Fruit size=5.1–5.7 cm diameter.

Immature cucumbers are normally used for fermentation. As the fruit matures, natural polygalacturonases, which are associated with ripening, are formed and consequently the seed area may liquefy during fermentation and storage.<sup>6</sup>

### 3.2. Microorganisms and their environment

Cucumbers are laden with numerous and variable microflora, but with a relatively small number of the lactic acid bacteria that are responsible for the desired fermentation.<sup>16</sup> Growth of the diverse microbial groups is dictated by the chemical and physical environment associated with brining. When brined, the cucumbers are transferred from an aerobic environment into a liquid, where anaerobiosis is established by respiration of the cucumber tissue.<sup>17</sup> The salt concentration dictates the types of microorganisms that can survive and proliferate.

The natural fermentation of cucumbers is unpredictable because of variations in the microorganisms on the raw fruit and variations in the environmental conditions that influence their growth. Naturally occurring lactic acid bacteria that are generally associated with vegetable fermentations include *Leuconostoc mesenteroides*, *Lactobacillus brevis*, *Pediococcus pentosaceus*, and *Lactobacillus plantarum*. The latter two species, being homofermentative, are preferred for the fermentation since high amounts of CO<sub>2</sub> from heterolactic fermentations can cause bloater formation. *Lactobacillus plantarum* normally terminates vegetable fermentations, apparently because of greater acid tolerance. Before lactic acid bacteria become established, however, they must predominate over various Gram positive and Gram negative bacteria. Yeasts may also proliferate during the natural fermentation of cucumbers. Fermentative yeasts may grow concomitantly with lactic acid bacteria and may continue growth after the lactic acid bacteria have been inhibited by low pH, provided that fermentable sugars remain. High concentrations of CO<sub>2</sub> from yeast fermentation may then result in bloater formation.<sup>18</sup>

## 4. Recent developments

### 4.1. Controlled fermentation

Controlled fermentation of cucumbers has been a long-sought goal in order to obtain consistent and predictable fermentations and a high quality product. A procedure for controlled



**Figure 3.** Flow chart of brine fermentation of cucumbers. Steps that have been added to the overall conventional procedure (natural fermentation) to render ‘controlled fermentation’ are indicated in upper case. Purging of CO<sub>2</sub> from brine continues until fermentation is essentially complete. Figure taken from Fleming.<sup>20</sup>

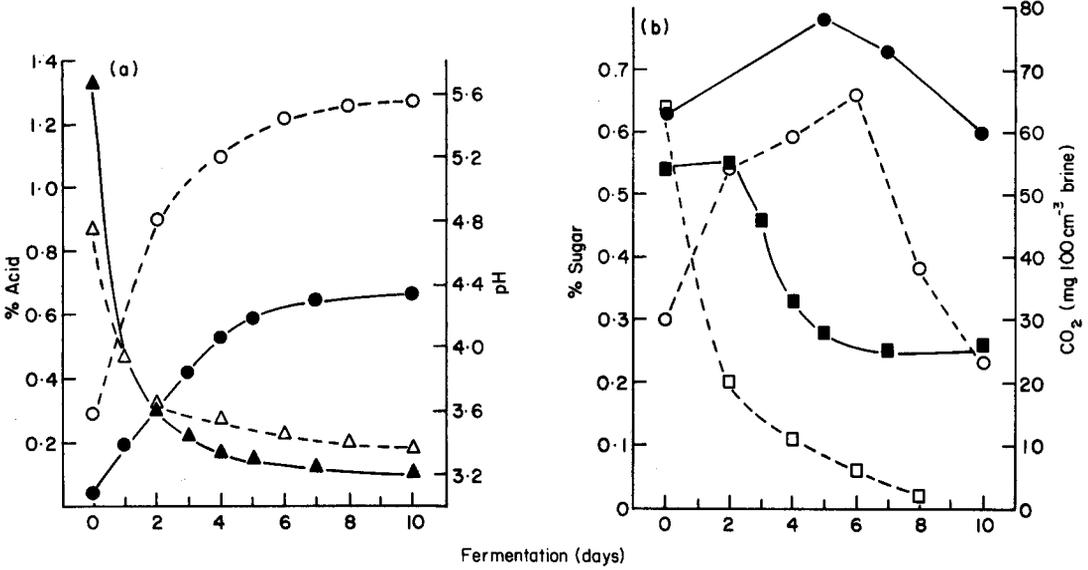
fermentation of cucumbers was introduced to the United States pickle industry in 1973.<sup>19</sup> Essentials of the procedure are summarised in Figure 3. The natural fermentation of cucumbers has been categorised into four distinct stages: initiation, primary fermentation, secondary fermentation and post fermentation<sup>20</sup> (Table 1). The controlled fermentation procedure outlined in Figure 3 is intended to eliminate two of these stages, initiation and secondary fermentation. Development of a suitable anaerobic tank for the pickle industry, discussed below, is intended to eliminate post-fermentation microbiological problems.

Initial acidification of the cover brine inhibits growth by acid-sensitive Gram positive and Gram negative bacteria and thus favours growth by lactic acid bacteria. The added acid is neutralised, or sodium acetate is added about 24 h after brining, before inoculation with a desired culture of lactic acid bacteria. This buffer not only makes the initial pH favourable for growth of the added culture, it also ensures fermentation of all sugars by the added culture. Without

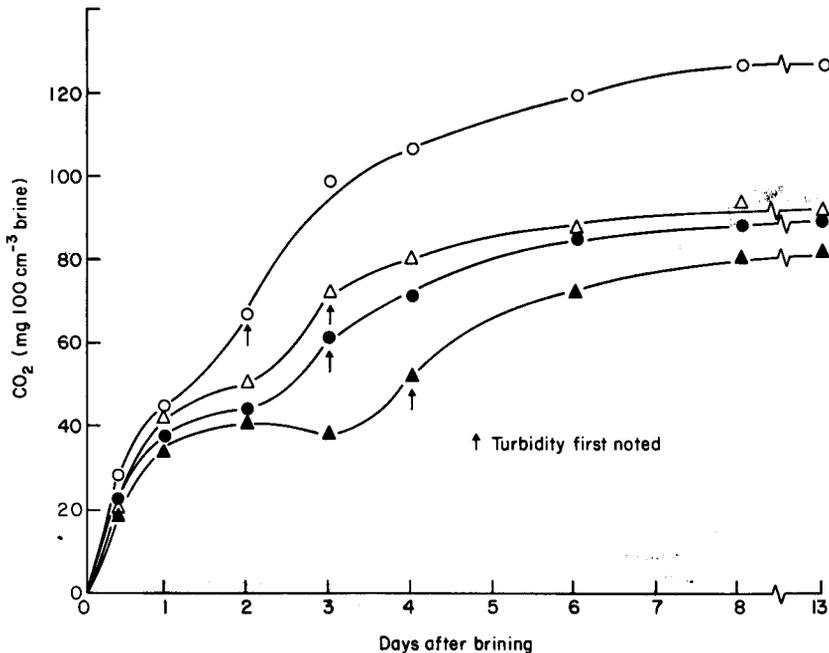
**Table 1.** Sequence of microbial types during natural fermentation of brined vegetables

Stage	Prevalent microorganisms
Initiation	Various Gram positive and Gram negative bacteria
Primary fermentation	Lactic acid bacteria, yeasts
Secondary fermentation	Yeasts
Post-fermentation	Open tanks <sup>a</sup> : surface growth of oxidative yeasts, moulds, and bacteria Anaerobic tanks: none

<sup>a</sup>Tanks with the brine surface exposed to the atmosphere. Exposure of the brine surface to sufficient sunlight will restrict surface growth, but surface growth may be great if the brine surface is shaded. Table taken from Fleming.<sup>20</sup>



**Figure 4.** Brine chemistry of cucumbers fermented by either controlled or natural fermentation. (a), acid production, controlled (○) and natural (●) and pH, controlled (△) and natural (▲). (b), sugar utilisation, controlled (□) and natural (■) and CO<sub>2</sub> production, controlled (○) and natural (●). Initial values obtained 1 day after brining and just prior to inoculation of the controlled fermentation. Figure taken from Etchells *et al.*<sup>39</sup>



**Figure 5.** CO<sub>2</sub> accumulation in cucumber brines undergoing fermentation by natural microflora at four concentrations of NaCl (○) 2.7% sat.; (△) 4.0% sat.; (●) 5.4% sat.; (▲) 7.0% sat. Figure taken from Fleming *et al.*<sup>40</sup>

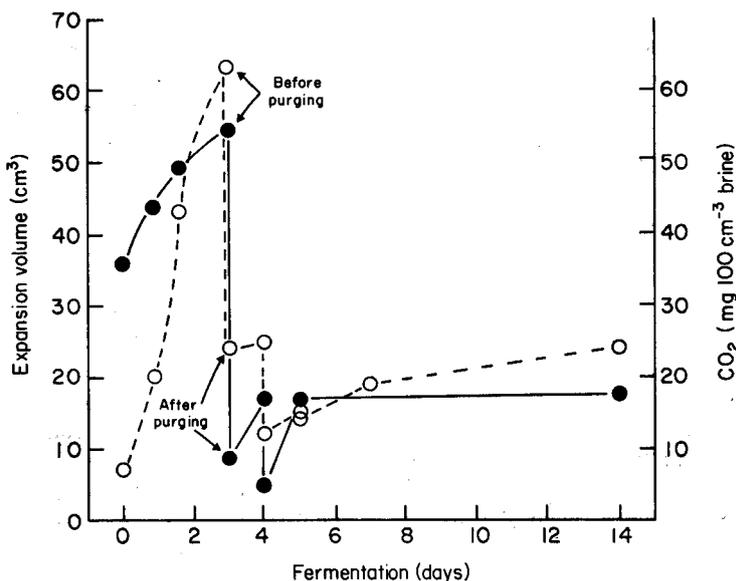


Figure 6. Effect of  $N_2$  purging on reducing the  $CO_2$  concentration (●) and expansion volume (○) of brined, Explorer variety cucumbers incubated at  $26.7^\circ C$ . The brine was purged for 2 h on the third, fourth, and fifth days of fermentation. Figure taken from Fleming *et al.*<sup>21</sup>

additional buffering, the cultures may be inhibited by low pH. The buffering, therefore, essentially eliminates secondary fermentation by yeasts. A comparison of the chemical changes that occur during natural versus controlled fermentation is illustrated in Figure 4.

The pickle industry has used controlled fermentation with *L. plantarum* and *P. pentosaceus* cultures, prepared by commercial firms, on a limited basis over the last 10 years. The industry has not adopted the entire procedure as outlined in Figure 3 for various reasons, which are discussed below. It has adopted the purging procedure, however, on a broad-scale basis.

#### 4.2. Purging

The production of  $CO_2$  in fermentation arises from the cucumber tissue and the fermenting microorganisms, resulting in bimodal appearance of  $CO_2$  in the brine surrounding the cucumbers (Figure 5). As  $CO_2$  concentration increases, gas pressure increases inside the cucumbers, causing internal gas pockets (bloating). Gas formation inside the tissue is accompanied by an increase in volume of the contents of the fermentation vessel, which permits an estimate of bloater formation as it occurs during fermentation without having to cut the cucumbers.<sup>21</sup> By bubbling  $N_2$  through the solution of the  $3.8 \text{ dm}^3$  containers of cucumbers, it was found that  $CO_2$  was removed from solution, which paralleled a decrease in volume inside the vessel, seen as a drop in brine level (Figure 6). The use of purging has increased steadily over the last 10 years and is now used by virtually every large cucumber brining company in the United States.<sup>22</sup> Nitrogen is the recommended gas for purging. It will also maintain anaerobiosis and thereby prevent problems arising from growth of moulds and other aerobic microorganisms, and oxidative changes that may result in undesirable flavours and colours. Air purging will effectively prevent bloater formation, but is not recommended because it encourages growth of aerobic microorganisms with possible undesirable effects.<sup>8</sup> Various sparging devices have been used, including perforated plastic tubing, ceramic diffusers, and porous plastic.<sup>22</sup> Initially, the sparger was placed in the bottom of the tank, but most companies now use various modifications of a side-arm gas lift device.<sup>23</sup> A sparger is placed near the bottom of the side-arm tube through which gas is introduced, resulting in the combined effects of purging to remove  $CO_2$  and brine circulation.

### 4.3. Gas exchange

A series of studies was pursued in an effort to understand more fully the mechanism of bloater formation.<sup>6,24,25</sup> These studies culminated in the hypothetical mechanism proposed in Figure 7. Gases move freely through stomata of the skin into and out of cucumbers held in a gaseous atmosphere (Figure 7A). A liquid layer is formed quickly around the perimeter of brined cucumbers. Gases must dissolve in and diffuse through this liquid before entering or exiting the cucumbers. The internal gas of cucumbers consists mostly of  $N_2$ , which has 1/80 the solubility of  $CO_2$  in water.  $CO_2$  produced by fermentation in the cover brine diffuses into the brined fruit faster than  $N_2$  diffuses out, resulting in a build up of gas pressure within the cucumbers (see Figure 7B).

Further efforts were made to determine effects of altering the internal gases of cucumbers before brining, on the physical properties of the brined cucumbers. One interesting observation was that cucumbers, when exchanged with  $O_2$ , behaved very differently from unexchanged fruit following brining. The  $O_2$ -exchanged and brined cucumbers obtained the translucent appearance normally associated with fully cured brine-stock cucumbers within hours, rather than weeks or months as is normally the case.<sup>26</sup> Also, buoyancy of the cucumbers, when held in the fermentation brine, was rapidly reduced. Studies have indicated that these unique physical properties of  $O_2$ -exchanged cucumbers are due to elimination of gas spaces within the fruit which are responsible for the raw, uncured appearance and relatively high buoyancy that are characteristic of freshly brined cucumbers. It was assumed that  $O_2$  in  $O_2$ -exchanged and brined cucumbers is quickly respired with resultant  $CO_2$  production. The  $CO_2$  is much more soluble in tissue fluids than the  $O_2$  that it replaced, resulting in reduced pressure within the brined fruit.<sup>6,26</sup> The occurrence of reduced pressure in  $O_2$ -exchanged and brined cucumbers has been confirmed.<sup>27</sup> Reduced pressure within the cucumber causes liquid to be drawn into the fruit, thus filling intercellular gas spaces.

Cured appearance is desired in brine-stock cucumbers because of its association with fully fermented cucumbers. Thus,  $O_2$  exchange could serve a useful function in this respect. Secondly, rapid loss in buoyancy could be advantageous because a lesser restraining force would be required to keep the cucumbers submerged in the brine solution, which is an important consideration in design of the fermentation vessel. Thirdly,  $O_2$ -exchanged cucumbers did not bloat during fermentation, even when the brines were not purged.<sup>26</sup> In pilot studies at a commercial pickle company, the first two observations in the laboratory studies cited above were repeated.<sup>28</sup> The cucumbers were seriously bloated, however, even when the brines were purged.<sup>28</sup> It was later found that bacteria are drawn into  $O_2$ -exchanged cucumbers, presumably accounting for bloater damage noted in the pilot studies.<sup>12</sup> The cucumbers were not washed in the pilot study but had been in the laboratory study. Washing may have removed the

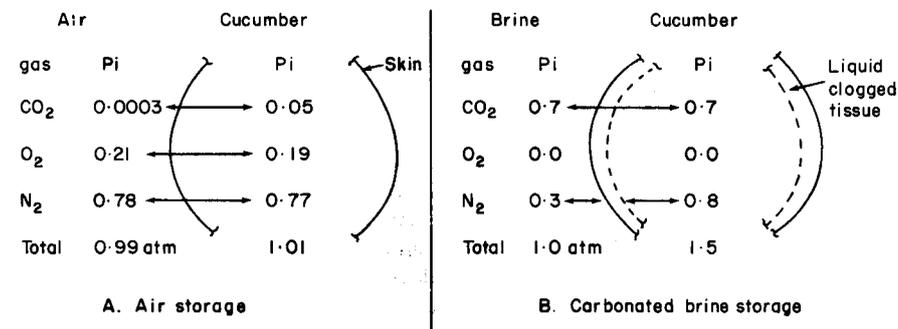


Figure 7. Hypothetical exchange of gases of cucumbers held in air and in carbonated brine. Pi is the partial pressure, in atmospheres. Figure taken from Fleming and Pharr.<sup>4</sup>

microorganisms from the cucumber surface in laboratory studies that had caused bloater damage in the unwashed cucumbers used in pilot-scale commercial studies.

#### 4.4. Lactic acid bacteria cultures

Four species of lactic acid bacteria and numerous species of yeasts may be involved during the primary fermentation of cucumbers (Table 2). *Lactobacillus plantarum* and *P. pentosaceus* have been chosen as the desired species of lactic acid bacteria for commercial cucumber fermentations. These species, being homofermentative, do not produce CO<sub>2</sub> from hexoses, and are preferred for the fermentation to minimise purging requirements. The particular strains used should be highly competitive with respect to growth and complete utilisation of sugars under the salt, acid, and temperature conditions employed during controlled fermentation, so as to minimise growth by naturally occurring gas-forming lactic acid bacteria and yeasts. Commercial cultures of both species have been available for several years; however, their use has not been widely accepted by the pickle industry. Two important factors contribute to this. Firstly, the tanks and general handling procedures used in cucumber fermentations to date are not highly compatible with use of pure cultures. Secondly, no strains of lactic acid bacteria that are sufficiently unique and valuable to mandate their use are commercially available.

Development of cultures of lactic acid bacteria with sufficiently valuable properties to encourage their use could provide additional impetus for the pickle industry to adopt controlled fermentation methods. The recent development of chemically mutated strains of *L. plantarum* that lack the ability to decarboxylate malic acid offers encouragement in this regard.<sup>29</sup> *Lactobacillus plantarum* and *P. pentosaceus* strains previously used, and apparently predominant in natural environments, decarboxylate malic acid to yield CO<sub>2</sub> and lactic acid.<sup>29,30</sup> Malic acid is a natural constituent of pickling cucumbers.<sup>31</sup> Decarboxylation of malic acid by cultures of *L. plantarum* normally used for cucumber fermentations was found to be an important source of CO<sub>2</sub> in relation to bloater formation.<sup>32</sup> An *L. plantarum* culture that lacks the ability to decarboxylate malic acid, but retains other desired properties, could be especially useful for cucumber fermentations. Predominant fermentation by such a culture could obviate the need for purging to remove CO<sub>2</sub> from the fermentation brine.

#### 4.5. Sugar removal

Complete and rapid conversion of fermentable sugars to lactic acid and stable end products is desired to shorten the time required for purging (economy), and to prevent gaseous secondary fermentation by yeasts. Sodium acetate,<sup>19</sup> sodium hydroxide neutralisation of previously added acetic acid,<sup>33</sup> and calcium acetate<sup>34</sup> have been used to provide adequate buffering to assure complete sugar utilisation. Calcium acetate serves a dual purpose, the acetate acts as a buffer and the calcium firms the tissue. Complete sugar utilisation in fermentation of cucumbers and other vegetables by *L. plantarum* was also accomplished by pH-controlled addition of NaOH.<sup>35</sup> This latter study confirmed an apparent but previously unestablished principle involving the

Table 2. Microorganisms involved during primary fermentation of brined cucumbers

Microorganism	Type	Principal end products from hexose fermentation
Lactic acid bacteria		
<i>Leuconostoc mesenteroides</i> <sup>a</sup>	Heterofermentative	Lactic acid, acetic acid, CO <sub>2</sub> , mannitol, ethanol
<i>Lactobacillus brevis</i>	Heterofermentative	Lactic acid, acetic acid, CO <sub>2</sub> , mannitol, ethanol
<i>Pediococcus pentosaceus</i>	Homofermentative	Lactic acid
<i>Lactobacillus plantarum</i>	Homofermentative	Lactic acid
Yeast <sup>b</sup>	Fermentative	Ethanol, CO <sub>2</sub>

<sup>a</sup>This species is not normally involved in cucumber fermentations because of its low salt tolerance, but could be important when cucumbers are fermented at low salt concentrations.

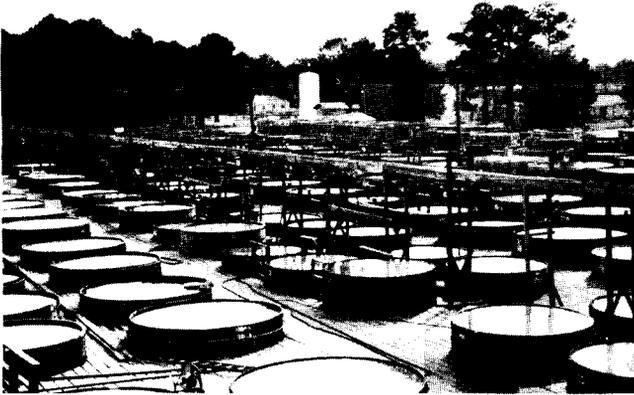
<sup>b</sup>Numerous species of fermentative yeasts have been associated with cucumber fermentations.<sup>18</sup>

importance of sugar removal in vegetable fermentations. That is, complete conversion of fermentable sugars to lactic acid and traces of other end products by *L. plantarum* will render the vegetables microbiologically stable, provided the pH is 3.8 or lower and the product is held anaerobically. The product may undergo enzymic changes, however, which result in tissue softening and off-flavours, depending upon the product.<sup>35</sup>

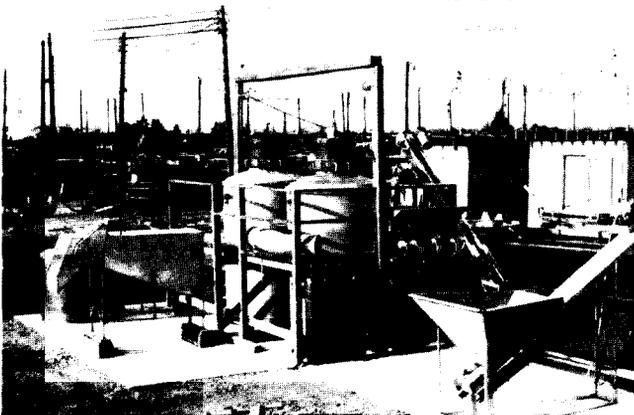
The possibility of using a yeast such as *Saccharomyces cerevisiae* in combination with lactic acid bacteria to ferment cucumbers has been considered.<sup>36</sup> Results indicated that such mixed culture fermentations may be useful in manipulating final acidity and sugar conversion to stable end products. The use of yeast would, of course, increase the requirement for purging. Further studies in this area are required.

#### 4.6. Low salt brining

Sodium chloride concentrations of 5–8% during fermentation and 10–16% during subsequent storage of cucumbers have been used to ensure against enzymic softening. The addition of calcium ions in the form of calcium acetate<sup>34</sup> or calcium chloride<sup>37</sup> has been found to allow fermentation and storage at lower salt concentrations. The US pickle industry has adopted use of  $\text{CaCl}_2$  on a wide basis, adding 0.2 to 0.35% of the tank contents of this compound. Although sodium chloride usage has been reduced because of the added protection against softening due to  $\text{Ca}^{2+}$ , the industry may be able to reduce salt usage further by adoption of improved tanks and controlled fermentation methods.



**Figure 8. Top.** A typical tank yard for brine storage of pickling cucumbers. The tops of the tanks are open to the atmosphere necessitating exposure of the brine surface to sunlight to prevent surface growth of yeasts and moulds. Note the tall, white tank in the center background that is used for liquid nitrogen storage. Nitrogen gas is piped to all tanks for use in purging of  $\text{CO}_2$  from fermenting brines to prevent bloater damage.



**Bottom.** Pilot project for development of an anaerobic tanking system for brined cucumbers. Two, 4160 dm<sup>3</sup> fibreglass tanks and accessory equipment for washing, loading and unloading the cucumbers are shown. Note the conventional open-top tanks in the background. Taken from Fleming *et al.*<sup>38</sup>

#### 4.7. Anaerobic tanks

The US pickle industry currently uses open tanks for fermentation of cucumbers (Figure 8, top). Many of the tanks are wooden and were obtained as discards from the distilling and brewing industries. Fibreglass tanks are becoming increasingly popular. The tanks are held outdoors so that sunlight strikes the brine surface; ultraviolet light prevents undesired growth of yeasts and moulds on the brine surface. If shaded, surface growth occurs and can result in various types of spoilage. Salt is added to compensate for rainwater and as additional insurance against softening and other spoilage. Industry-sponsored pilot studies are currently underway to develop closed-top, anaerobic tanks for the industry (Figure 8, bottom).<sup>38</sup> Use of such tanks could place the pickle industry in a position for considerable technological advancement analogous to changes that have occurred in the brewing, wine, and other fermentation industries during this century.

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