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Nilgun Aksoy Erdal

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FACTORS AFFECTING QUALITY OF SALT-STOCK CUCUMBERS

By

Nilgun Aksoy Erdal

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ABSTRACT

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OF SALT-STOCK CUCUMBERS

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The factors affecting the quality of salt-stock cucumbers were evaluated. Results indicated increased bloater-type defects on salt-stock cucumbers held 30 hours at 30°C before brining. MSU control-seedless cucumbers resulted in superior quality compared to commercial-seeded salt-stock cucumbers.

Slice punching (r=0.76) and side crushing (r=0.86) Instron values showed a good correlation between green-stock and salt-stock measurements.

Calcium determination on firm and soft salt-stock cucumbers indicated that firm salt-stock contained higher calcium (225 ppm) than did the soft stock (180 ppm).

Pectinolytic enzyme activity studies indicated that the enzyme was more highly active in the interior of the salt-stock cucumbers than in the exterior portions. The high enzyme activity increased the percent bloater-type defects and soft centers. The firmness of the salt-stock was found to be in direct relationship to salt concentration and inversely related to the activity of the pectinolytic enzymes.

To my parents

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INTRODUCTION

The preparation of salt-stock pickles is a commercial procedure designed to handle a large quantity of cucumbers within a short harvest season. Pickles have been prepared in homes throughout the world for centuries and they remain the universal favorite among fermented vegetable products. They are not so much known for nutritional value as they are for the pleasure and enjoyment of their consumption.

Although their precise origins are unknown, the methods of preservation of vegetable substances by fermentation presumably originated in the Orient. Practices continued for centuries with little standardization until the early period of this century. Technique improvements in the pickle industry were developed during a span of centuries.

There are no figures of worldwide consumption data for fermented vegetables. In many areas of the world fermentation is the only method used for preserving vegetables, and they are prepared almost entirely in the homes. Pickles are presently a significant part of the diet of the Far Eastern peoples, the Europeans, and Americans. Since 1931, the increase in consumption of pickles in the U.S. has exceeded that of nearly all other food commodities. Since 1955, pickle consumption has increased over 100%. Per capita consumption has increased from about 2 1/2 lb. in the early 1930's to about 8 lb. in 1971. Michigan is a leading state in cucumber production. In 1977 the pickle production in Michigan was 114,000 tons.

Pickle research has been conducted to bring about more efficient production and processing of improved pickles for the consumer. During the fermentation process bloating and softening of commercially brined cucumbers result in a million dollar loss each year to the U.S. pickle industry. Cucumbers brined and fermented for storage as salt-stock pickles are very susceptible to bloater-type defects. These are usually due to the accumulation of gaseous CO_2 in the cucumber tissue. The extent of damage varies with the amount of gas released in the tissue. To help lower the CO_2 content to a level that would minimize bloater formation, a nitrogen-gas purging system is used. With this system the bubbling action of the nitrogen gas up through the brined cucumbers carries the CO_2 to the brine surface and allows it to escape into the atmosphere. Some conditions which affect CO_2 bloating include (1) brine strength, (2) brine temperature, (3) tank configuration, (4) cucumber-to-brine ratio, (5) cucumber size and (6) chemical composition of the brine.

Enzymatic softening is the second problem that the pickle industry often encounters. The nature of this softening action has been considered to be the result of action by pectin-splitting enzymes on the pectin composing the middle lamella of cucumber tissue. At such times the cucumbers, referred to as salt-stock, may either lose their firmness completely, becoming mushy, or they may develop soft centers. Pectic substances act as cementing material between the cells and play an important role in firmness or texture quality. The presence of pectinase in cucumber brine is correlated with the softness of the salt-stock and the latter condition is attributed to the breakdown of pectic substances.

This study was conducted in two parts. The primary objectives of the first part were: (a) to determine the effect of different salt concentrations (30^{o}, 40^{o} and 50^{o} salometers) on salt-stock quality, (b) to observe the seedless and seeded cucumbers as salt-stock, and (c) to determine the effect of holding the cucumbers at a certain temperature before brining.

In the second part of the study enzymatic activity of pectinase was determined in different treated salt-stock brines during the fermentation. For this purpose cucumbers were brined with soft brine, firm brine, soft pickle, firm pickle, outside and inside of soft and firm pickles, and sorbate. The effect of different salt concentrations on enzyme activity was also studied.

REVIEW OF LITERATURE

Post Harvest Conditions of Green Stock Cucumbers

Mechanical harvesting of cucumbers caused higher mass losses than did harvesting by hand, although it affected no differences in proportions lost due to rotting (Garte and Weichmann, 1974). Marshall and Levin (1976) reported that many factors (and their interactions) of cucumber harvesting and handling may contribute to overall reduced brine stock quality. Impact loading was a dominant factor indicating drop height should be used. To minimize abrasion and damage every effort must be made to reduce physical handling of cucumbers.

Garte and Weichmann (1974) observed that pickling fruit harvested by machine has a 6 to 20% higher rate of respiration than that harvested by hand. Consequently, prompt precooling of such fruit is particularly important because respiratory heat can accumulate rapidly in bins. Thus, unwashed fruit retained "acceptable" quality 6 days at 4.5^{o}C (40^{o}F), but washed fruit retained it for less than 4 days (Pflug et al., 1960).

Cucumbers can be expected to remain in good condition for 10 to 14 days at 10^{o}C (50^{o}F). For fruits harvested relatively young, where yellowing is not an immediate problem, 13^{o}C (55^{o}F) would be preferable and may extend the storage life 2 or 3 days. Proper controlled atmosphere conditions may add an additional 4 to 6 days for a total of about 3 weeks good storage life (Ryall and Lipton, 1978).

Fellers and Pflug (1967) reported that regular and controlled-atmosphere (CA) refrigerated storage life of pickling cucumbers were

found to be highly dependent on size of fruit, storage temperature, and whether or not fruit underwent washing prior to storage. No. 1 and 2 sizes were stored successfully in regular refrigerated storage at 1.1°C (34°F) and 4.4°C (40°F) for about 3 to 6 days, and no. 3's for a period somewhat longer than 9 days. Washing fruit reduced storage life to half that of unwashed fruit. Storage temperatures in excess of 4.4°C (40°F) were found deleterious to quality, especially flavor, and to skin and flesh color characteristics. Refrigerated CA storage at 1.1°C (34°F) or 4.4°C (40°F) extended the storage life of pickling cucumbers by 2 weeks for no. 2's and 3 weeks for no. 3's. The best combination of temperature and atmosphere was 1.1°C (34°F) at 5% CO_2 and 5% O_2.

Pickling cucumbers are subject to chilling injury if held longer than about 2 days at temperatures below 7.2°C (45°F). At temperatures 10°C (50°F) and above, they ripen rather rapidly, the green color changing to yellow. Yellowing is a sign of senescence and those cucumbers are unattractive. Yellowing is accelerated by warm temperatures and the presence of ethylene in the air (Morris and Mann, 1946). During any storage of cucumbers, be it in transit or in a cold room, ethylene must be scrupulously avoided. According to Apeland (1961), even 1 ppm will cause noticeable yellowing in one day at 15°C (59°F).

Joffe (1959) detected significant softening in pickling cucumbers after holding only 16 hours at 4.4°C (40°F).

Fleming et al. (1968) observed and suggested that the characteristic flavor components of fresh cucumbers are generated enzymatically as a consequence of cutting or mechanically rupturing the cucumber fruit.

The sugar content of cucumbers is of great interest to the pickle industry since it serves as substrate for the fermenting organisms involved. Any residual sugar remaining after the primary fermentation may serve as an energy or carbon source for secondary fermentations.

McCombs et al. (1976) analyzed cucumbers for sugar and dry matter content shortly after harvest and after a 3-day storage period (16^{o}C). Their study indicated that the storage period produced no consistent pattern of differences in reducing and total sugars and dry matter content. Large fruits had more sugar than small fruits. Fructose, glucose and sucrose were shown to be present. Nearly all of the sugar present was reducing sugar. The sugar concentration was higher in locule tissue than in the carpel wall tissue.

On the other hand, Fleming et al. (1973a) reported that thin layer chromatography of extracts from fresh cucumbers indicated that glucose and fructose constituted the major portion of sugars present. Only traces of other unidentified sugars were found and sucrose was not detected.

In a study conducted by McCreight et al. (1978), reducing sugar and total carbohydrate concentration were highly correlated, but were not highly correlated with fruit size or fruit fresh weight. Over two harvests, sugar concentration varied; for the first harvest, reducing sugar averaged 31.1 mg/g and for the second harvest, it averaged 22.6 mg/g. They also observed that reducing sugar concentration did not change in frozen storage through 180 days. Sugar concentration of frozen samples, which were prepared after thawing, did not differ significantly from the fresh samples.

Pharr et al. (1977) reported the major sugars of cucumber fruit as glucose, fructose, and sucrose. Stachyose was present in small fruit but no soluble galactose containing saccharides were found in larger fruit. It was also found that four species of lactic acid bacteria from cucumber fermentations were able to ferment stachyose, raffinose, sucrose, galactose, glucose and fructose.

Baker et al. (1973) developed a new concept in pickles, termed "seedless pickles." Seedless pickles are more adaptable to mechanization, including postharvest handling, since fruits remain firm and usable longer than seeded fruits which soften during seed maturation. These workers also concluded that increased raw product efficiency, related to firmer green stock and brine stock, lowers processing costs for a superior finished product. Consumers presumably would prefer seedless pickles because of their attractiveness and superior culinary characteristics described as crunchy, firm and fleshy.

Salt-Stock

Natural Fermentation--Controlled Fermentation

The growth of the naturally occurring microbes, introduced by the cucumber, is called "natural fermentation." In the pickle industry cucumbers are usually fermented by "natural fermentation" in wooden tanks containing salt brine of suitable strength. A common commercial salting procedure used in the industry is briefly outlined as follows: the cucumbers are immersed in a brine (40-45^{o} salometer), the tanks are first held at 25-28^{o} salometer until the acidity is increased and, then additional salt is added at intervals in order to raise the salt concentration to about 40-45^{o} salometer. The final concentration of salt

should be high enough, in combination with the acid produced by fermentation, that enzyme action will be inhibited and the brine will not freeze during the winter months.

The complex changes that occur in natural fermentation are produced by the growth of a sequence of lactic acid bacteria. The brine becomes increasingly cloudy for the first few days due to growth of bacteria. The microbes that cause the natural fermentation come chiefly from the cucumbers and adhering particles of soil. Their growth depends upon their initial population on the cucumber, the sugar content, salt concentration of brine and the environmental temperature. They feed on the soluble, nutritive materials, especially sugars, that diffuse into the brine as the result of the action of the salt brine on the cucumber tissue.

Lactobacillus plantarum was considered the cucumber fermenter (Breed et al., 1948). Later studies have also shown that this bacterium is the active acid forming bacteria during the natural fermentation, and in both commercial and laboratory conditions, it starts rapid growth in cucumber brines within 24 hours after brining (Costilow and Fabian, 1953).

As it is understood, during the natural fermentation of brined cucumbers, non-gas forming species of lactic acid bacteria are desirable. In addition to the non-gaseous species, microorganisms which produce large amounts of CO_2, such as coliform bacteria (Etchells et al., 1945), yeasts and heterofermentative lactic acid bacteria (Etchells et al., 1968), may also be active in the brine.

Bloater-type defects occur in large size brined cucumbers as a result of the accumulation of gaseous CO_2 in the cucumber tissue (Jones et al., 1941). For many years, it was believed that gas production was primarily due to fermentative yeasts and that bloater-type damage could be controlled by preventing yeast growth. Phillips and Mundt (1950) first suggested the use of sorbic acid in cucumber brines to control the yeast growth. Costilow et al. (1955 and 1957) reported that sorbic acid treatment reduced the percentage of bloater spoilage but bleaching of the salt stock occurred in some cases. Fleming et al. (1973b) have shown that a considerable amount of CO_2 accumulated in brines without any significant yeast activity. Finally, the CO_2 gas was attributed to cucumber respiration and to the homofermentative lactic acid bacterium, Lactobacillus plantarum (Etchells and Fleming, 1975).

A system was developed using nitrogen gas to purge the brines during the fermentation and to maintain low CO_2 concentrations (Etchells et al., 1973).

Costilow and Bedford (1977) reported that it was possible to greatly reduce the build up of CO_2 in salt stock pickle brines undergoing natural fermentations and to greatly reduce the incidence of severe bloater-type spoilage by use of an efficient purging system. A side arm purging system gave the best result in reduction of CO_2 level in brine. In this system a gas diffuser with a very small pore size was used to purge the brine while the brine was being circulated.

In contrast, Fleming et al. (1975) did not observe any significant reduction in the percentage of bloaters by purging the salt stock undergoing natural fermentation.

Some researchers believe that natural fermentation is highly complex, unrestricted, heterogeneous and variable. They also assume that this kind of natural fermentation leads not only to too much variation between fermentations, but it also can be responsible for certain defects and various types of deterioration and spoilage of cured brine-stock (Etchells et al., 1973).

Under these assumptions, natural fermentation spawned new ideas in pickle fermentation. Etchells et al. (1973) suggested using controlled lactic acid fermentation of cucumbers in order to eliminate or minimize the usual defects of brine-stock pickles. Controlled fermentation involves washing the cucumbers, chlorination and acidification of the cover brine, addition of sodium acetate as a buffer, inoculation of the brine with a starter culture of L. plantarum, and purging of dissolved CO_2 from the brine with nitrogen. Figure 1 shows the procedures for controlled and natural fermentations of green stock cucumbers. In controlled fermentation, inoculation is usually made with a special strain of L. plantarum which is very acid tolerant and capable of rapidly fermenting out all of the sugars. In some instances Pediococcus cerevisiae is added because of its good growth at rather high salt concentrations. In this case, P. cerevisiae initiates the fermentation, and is then succeeded by the more acid-tolerant L. plantarum which continues to produce acid until all of the sugar is used. The buffer additive usually holds the final brine pH from about 3.4 to 3.5 even after all the brine sugars are fermented (Etchells et al., 1973).

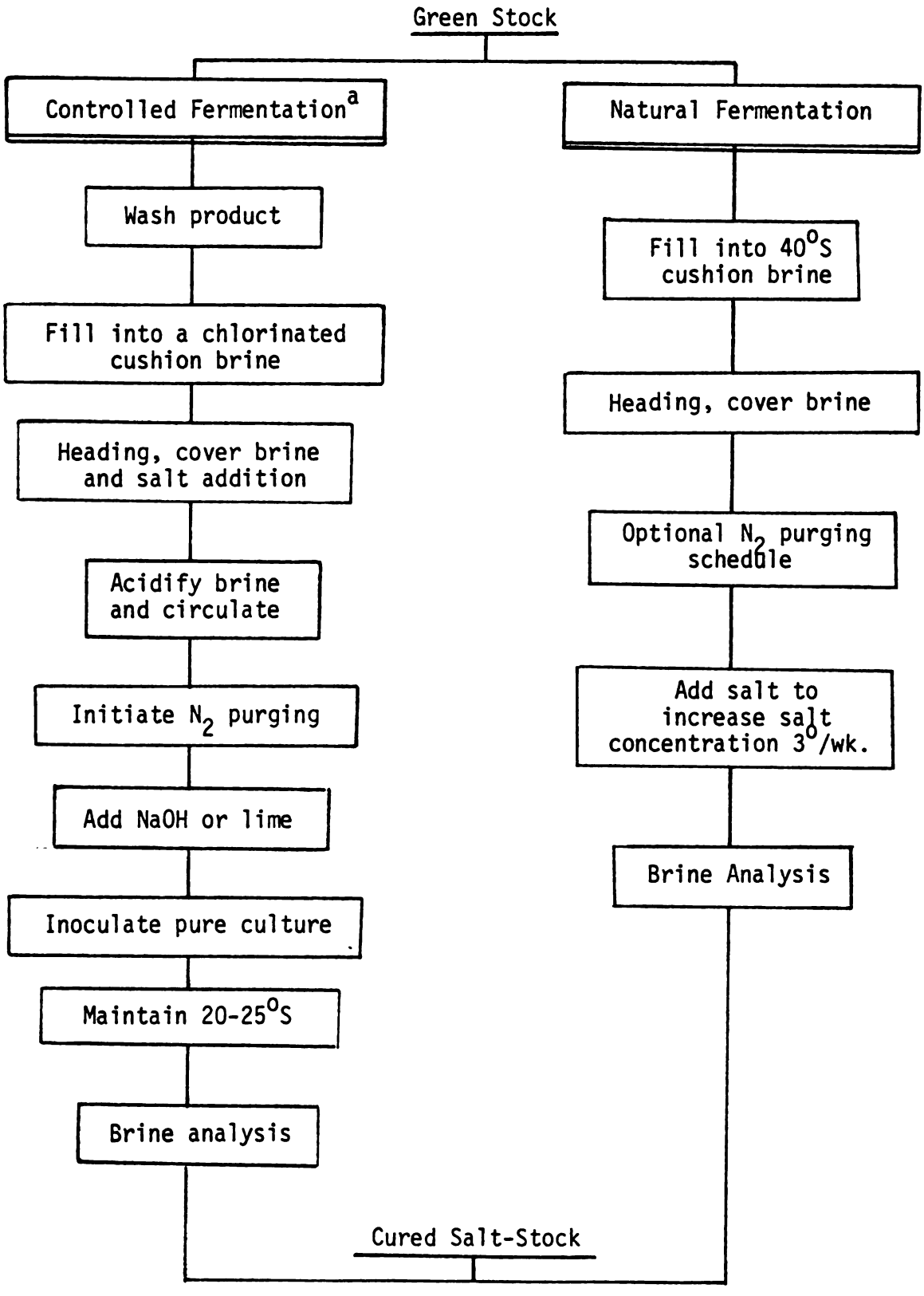


Figure 1. Generalized procedures for controlled and natural fermentations.

[a]Modified from Lingle (1975).

Changes During Fermentation

When cucumbers are placed in brine they undergo rapid physical and chemical changes. The water is withdrawn from the cucumbers: the cucumbers lose weight while the brine becomes dilute. The brine also causes the cells of the cucumber tissue to become permeable. This disorganization of the tissue permits the diffusion of soluble cellular constituents such as sugar and other organic substances from the cucumbers into the brine, and of salt from the brine back into the cucumbers. During the first 48 hours of the salting process, the brine causes a loss in weight of the cucumber, due to loss of water and soluble substances. Following this, there is a slower but prolonged gain in weight due primarily to diffusion of salt into the cucumbers. Shortly after the semipermeability of the cucumber tissue has been destroyed and sugar has diffused into the brine, microorganisms on the surfaces of the cucumbers start an active fermentation (Jones and Etchells, 1943). The lactic acid fermentation usually involves at least three species of acid forming bacteria, namely, Pediococcus cereviciae, Lactobacillus plantarum, and L. brevis (Pederson and Albury, 1950).

Change in Brine-Sugar Concentration. The diffusion of sugar from the cucumbers into the brine begins immediately after the cucumbers are salted. The microorganisms utilize the sugar and perhaps other organic substances and consequently these organic substances disappear or are reduced to a very low level as the fermentation proceeds. The decrease in brine-sugar concentration is the result of the activity of microorganisms (Jones and Etchells, 1943).

Fleming et al. (1973b) reported that, during the fermentation, no sugar remained after 13 days in 2.7 and 4% brines (after equilibration). In 5.4 and 7% brines the residual sugar was present. After 36 days sugar remained in the 7% brine but not in the 5.4% brine. When the three cultures of homofermentative lactic acid bacteria, L. plantarum WSO; L. plantarum 442 and P. cerevisiae 39, were compared regarding the amounts (%) of residual sugar in the brines, it was found that less residual sugar was available at the end of fermentation inoculated with L. plantarum WSO. On the other hand, the amount of residual sugar was considerably higher in the brine inoculated with P. cerevisiae.

Etchells and Fleming (1975) reported that 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. They also observed that in controlled fermentations of brined cucumbers, fermentable sugars were rapidly and completely converted to acid, usually within 7-10 days. 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.

Brine Acidity. Through the activity of the microorganisms, many end-products are formed, including gases, organic acids, alcohols and other compounds, some of which may be formed in small quantities. Acidity is determined by titration and is expressed as lactic acid. The formation of acid begins very soon after the cucumbers have been brined and continues at a rapid rate for the first 10 to 12 days.

Brine acidity is affected by brine concentration. Acidity reached 0.7, 0.4 and 0.2% lactic acid levels in 14 days at 20^{o}, 40^{o}, and 60^{o} initial salometers respectively (Jones et al., 1941).

Etchells and Fleming (1975) reported that acidity has reached 1.0% in controlled fermentation where as it was only 0.6% in natural fermentation. It is a well known fact that the higher the salt concentration, the greater will be its inhibiting effect upon growth of lactic acid bacteria and the lower the amount of acid will be produced. In an 8% salt solution there is less acid produced than in a 2% salt solution.

pH Change. Concomitant with the formation of acid there is a corresponding change in hydrogen ion concentration. In 20^{o} salometer brine the pH went from 6.5 to 3.5 in 3 days and at 60^{o} salometer it reached 4.2 in 14 days (Jones and Etchells, 1943).

Color Change. Most obvious is a change in the color of the cut cucumber from a variable white, opaque transluency to a uniform darker, olive green transparency.

Bacteriological Change. Etchells and Fleming (1975) reported that brines from controlled fermentation 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.

Gas Evolution. Both the cucumbers and the bacteria in the fermenting brine contribute to the amount of CO_2 that accumulates in the brine (Fleming et al., 1973a). The CO_2 diffused from the cucumbers into the brine prior to the onset of bacterial growth in the brine (Fleming et al., 1973b). Etchells et al. (1945) reported that quantitative CO_2 production has been based on the CO_2 that evolved from the fermentation.

Fleming et al. (1975) observed that the dissolved CO_2 concentration was from 30 to 40 mg/100 ml brine after 1 day. The CO_2 concentration reached 85 mg/100 ml brine in 4 days in non-purged natural fermentation pails and reached 70 mg/100 ml in controlled fermentation pails. Nitrogen purged pails contained 5 to 15 mg/100 ml brine CO_2 after 4 days of fermentation.

Quality of Salt Stock

Every year the pickling industry experiences considerable losses due to bloating and softening of pickles in brine.

Bloating of Salt Stock. Cucumbers brined and fermented for storage as salt-stock pickles are very susceptible to bloater-type defects. Bloating is a problem in both natural and controlled fermentation. These bloater-type defects are usually due to the accumulation of CO_2 gas in the cucumber tissue (Jones et al., 1941; Etchells et al., 1968; Fleming et al., 1973a and 1975). 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 (Fleming et al., 1978).

Fleming et al. (1973a) reported that a considerable amount of CO_2 accumulated in brines without any significant yeast activity. The gas was attributed to cucumber respiration and to the homofermentative lactic acid bacterium, Lactobacillus plantarum. The extent of damage varied with the amount of gas released from these sources.

The mechanism for bloater formation is described in a study done by Etchells et al. (1968). These workers reported that the fermentation gas, which is produced solely in the cover brine, diffuses into the cucumber via the brine in a supersaturated state and is released and accumulates at a location of structural weakness inside the cucumber fruit. Where the three carpels are joined is such an area and balloon-type bloating results. The gelatinous area around individual seeds is also susceptible and bloating results, first appearing as the honeycomb defect, which, under continued stress of the gaseous fermentation, may develop into typical lens-type bloater damage. Fleming et al. (1978) explained a similar mechanism of bloater formation except that the brine of freshly brined cucumbers does not have to be supersaturated with CO_2.

It is a known fact that bloater damage is a more serious problem in the larger size cucumbers. No evidence of bloating was found for no. 1 cucumbers, whereas, nos. 2 and 3 were severely bloated after 3 weeks of fermentation (Fleming et al., 1973a).

Mechanical harvesting causes more damage to cucumbers than does hand harvesting (Marshall et al., 1972), and thus a higher incidence of bloater formation may result.

Factors influencing the solubility of CO_2 are related to bloater development in cucumbers. The solubility of CO_2 is reduced at higher temperatures and NaCl concentrations (Quinn and Jones, 1936).

Fleming et al. (1973a) reported that increased fermentation temperature accelerates the bloating damage of brined cucumbers. In their study, bloating occurred in 92% of the cucumbers fermented at 32.2°C and had reached advanced stages after 3 weeks. At 21.1°C no balloon bloating was evident and only 11% of the cucumbers had honeycomb defects.

In another study conducted by Etchells and Fleming (1975) it was concluded that 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. These workers also reported that bloater damage decreased at lower packout ratios (cucumber : brine); the percent of total bloaters was significantly higher at a ratio of 65:35 than at 45:55. It can be assumed that the smaller proportion of cucumbers would be expected to give off less CO_2, which would be dissolved in the larger volume of brine. Furthermore, fewer brine sugars would be available by microbial metabolism for CO_2 production.

Effect of brine depth on physical qualities of brine stock has been studied by several investigators. Etchells and Fleming (1975) reported that there was more bloater damage in cucumbers brined at greater depths. 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. On the other hand, Fleming et al. (1977) demonstrated that the extent of bloater damage varied directly with CO_2 concentration, hydrostatic pressure, and buoyancy pressure,

which are three primary factors influenced by brine depth. Increased hydrostatic pressures gave greater resistance to bloater formation. Buoyancy pressure of cucumbers may cause physical damage of the cucumbers in upper regions of brining tanks, even when CO_2 is purged from the brine.

Maturity of cucumbers is another factor affecting the bloater formation in salt stock. Pederson and Albury (1962) reported that mature cucumbers yielded a higher percentage of bloater stock than did immature stock. Mature cucumbers absorbed salt brine considerably more slowly than immature cucumbers. Their study also proved that bloater damage increased when cucumbers were held 2, 3 and 4 days at 21.1°C (70°F) before brining.

Etchells et al. (1973) suggested purging the controlled fermentation brines with nitrogen gas to maintain low CO_2 concentrations, in order to prevent bloater-type damages. Removal of dissolved CO_2 from brines by purging with nitrogen gas reduced or eliminated bloater damage (Fleming et al., 1973a).

Fleming et al. (1975) observed that the percent of pickles with bloater damage from controlled fermentations was at a maximum 2 days after brining. Therefore it is very important to start purging immediately after covering the cucumbers with brine. Bubbles of nitrogen introduced into the bottom of the cucumber brine absorbed CO_2 as they rose through the solution. Air which is about 80% nitrogen, and other gases of low solubilities in aqueous solutions, probably would also purge CO_2. Nitrogen is preferred over air as the purging gas. Air does remove CO_2 from brine, but the resulting effect on quality factors such as loss of firmness and discoloration of the cured cucumbers restricts its use for purging. The rate of CO_2 removal is affected by the hydrogen concentration.

At pH 4.5 and 3.5 there is an increased conversion of CO_2 to bicarbonate. As the pH rises to 7, the rate of removal is considerably lower than at the pH 4.5 and 3.5. Bubble size is also effective in removal of CO_2 gas. Smaller bubbles provide more surface area per unit of purging gas than larger bubbles, and should be more efficient in removing CO_2 from the brine. Fleming et al. (1975) also studied the effects of various nitrogen flow rates on CO_2 removal from brines. They concluded that continuous purging at nitrogen flow rates of 5 to 100 ml/min. reduced and maintained CO_2 concentrations in the brine below the initial values.

Costilow and Bedford (1977) reported that it is possible to greatly reduce the build up of CO_2 in salt stock pickle brines undergoing natural fermentations and to greatly reduce the incidence of severe bloater-type damage by use of an efficient purging procedure. These workers designed three purging systems: an overhead system, side arm purger, and bottom purger. The results indicated that the side arm purger was very effective in controlling CO_2 levels in salt stock brines. In this system a gas diffuser with a very small pore size was used to purge the brine while the brine was being circulated.

Costilow and Bedford (1977) found that there were no significant differences between the controlled fermentation system and the purged natural fermentation system for either CO_2 concentrations or percentages of serious defects in the pickles.

Fleming et al. (1975) reported that purging of natural fermentations in closed pails with nitrogen reduced the total percentage of bloaters, but the reduction was not as striking as was observed with controlled fermentations.

Shoup (1975) reported that salt-free acidulant storage of pickling cucumbers with 4.4% acetic acid yielded 27.5% bloater damage, whereas salt brine treatments yielded values of 75% damage. Furthermore the flavor acceptability of acetic acid treated pickles was quite high.

Enzymatic Softening of Salt-Stock. Enzymatic softening of cucumbers during brine fermentation and storage is a problem that the pickle industry confronts each year. This type of spoilage creates a considerable economic loss for the pickle industry.

Pectic and cellulosic substances are the most abundant organic materials in fruits and vegetables and their chemical changes have been related to texture and quality in food processing (Weier and Stocking, 1949). In general, cellulosic substances make up the primary structural element in the cell walls of plants, and these cells are held together by pectic materials.

The softening of cucumbers brined under commercial conditions was first shown by Bell and Etchells (1950) to be enzymatic in nature and the direct result of hydrolytic action by an enzyme system. In their study they reported that the seeds, leaves, petioles, stems, flowers and fruit of pickling cucumbers were found to contain the deesterifying pectic enzyme, pectinesterase. The optimum activity of this enzyme was pH 7.5 and maximum electrolyte concentration was between 0.15 and 0.20 M sodium chloride in pectin substrate. The activity in both the extracted cucumber juice and in the brine was low compared to that observed in the non-brined green cucumbers. The low activity was attributed chiefly to enzyme inactivation caused by the acid resulting from the lactic acid fermentation.

In his later study Bell et al. (1951) also found out that the cucumber plant and fruit (Cucumis sativus) was a source of a pectolytic enzyme as measured by a loss in viscosity of a pectin solution. The enzyme of the cucumber was strongly active in the seeds, staminate, pollinated pistillate flowers, and ripe fruit but was not found in the unpollinated flowers, leaves, petioles and stems.

Etchells and Bell (1955) reported that pectinolytic and cellulolytic enzymes were introduced into the fermentation by mold-laden flowers attached to the green cucumbers. Brine samples from vats filled with small cucumbers that had a high percentage of flowers were shown to contain high enzyme activity and, in general, the salt stock was either soft or inferior in firmness. When the retained flowers were removed and the cucumbers thoroughly washed, the brine samples were very low in enzyme activity and the stock was exceptionally firm.

Etchells et al. (1958a) concluded that flowers were a potent source of softening enzymes in commercial cucumber brines. Further it was believed that the softening enzyme systems were introduced into curing brines chiefly by way of the fungus-laden flowers that remained attached to the cucumbers, and to a lesser extent by the fruit itself. Raymond et al. (1959) demonstrated that the maximum concentration of softening enzymes diffused out of the flowers and into the brine within 24 to 48 hours after the vats were filled. Etchells and Bell (1955) suggested the draining off of the original enzyme-laden cover brine 36 to 48 hours after filling, and replacing it with a new brine. This work also proved that blossoms, either fresh or withered, were a source of great pectin splitting activity. Salt-stock from early harvested cucumbers contained

about five times as many cucumber blossoms as did similar salt-stock from the late harvested crop. By the removal of all blossoms from the cucumbers, even during the early portion of the harvest period, firm salt-stock could be obtained.

Research in northern production areas, such as Michigan, Wisconsin, and Indiana, was conducted by Bell and Etchells (1958). Retained cucumber flowers from these areas possess a potential softening enzyme activity equal to that of flowers from southern areas and if sufficient amount of these were introduced into curing vats, they could reduce the firmness of brined material.

To eliminate or significantly reduce the concentration of softening enzymes in commercial cucumber brines, specific nontoxic inhibitors of plant origin were studied. Etchells et al. (1958b) first demonstrated that the pectinolytic and cellulolytic enzymes in cucumber flowers, were effectively reduced in activity by the use of a crude extract of Scuppernong grape leaves. There was no apparent influence of the grape leaf inhibition on the character of the acid fermentation as measured by total acidity, pH and optical density of the brine. Higher levels of inhibitor resulted in an increase in firmness of the fermented cucumbers. Bell et al. (1960) reported that a water soluble substance in grape leaves inhibits the enzymatic hydrolysis of soluble cellulose. Bell and Etchells (1961) tried to identify the pectinase inhibitor in grape leaves. They concluded that Scuppernong grape leaves contained a tannin or a tannin-like compound. Six grape varieties were tested and the leaves from the Scuppernong variety of the muscadine group illustrated the highest inhibitor effect (Bell and Etchells, 1958).

Lampi et al. (1958) observed that pectolytic enzymes cause softening of salt stock pickles. However certain varieties were firm even in the presence of high pectolytic enzyme activity in the brines. It was concluded that the development of softness in cucumber salt-stcok was accompanied by a conversion of the acid soluble pectic substances (protopectin) to soluble pectic substances (pectinic acid). Their study also indicated that there was no correlation between calcium contents of the tissues and firmness. Calcium seemed to be higher in the softer salt-stock. Therefore, no correlation between firmness as measured by the fruit pressure tester and calcium contents of the tissues could be made.

In another study, Bell et al. (1965) reported that pectinolytic and cellulolytic enzymes in cucumber flowers were effectively reduced in activity by the use of a brine extract of sericea and by a freeze-dried substance isolated from this plant. Higher levels of the inhibitor resulted in an increase in firmness of the cured salt stock cucumbers.

The influence of salt concentration on the pectinolytic softening of cucumbers has also been studied. Etchells and Jones (1951) reported that the use of low salt brining procedures for cucumbers results in more softening losses than the use of higher brine strengths. Bell and Etchells (1961) showed that the use of increasingly higher salt concentrations gave correspondingly higher values for cucumber firmness. Also, an increase in enzyme concentration resulted in a decrease in cucumber firmness at all levels of salt concentration. The rate of enzyme action was very rapid at the lower salt levels and a higher degree of cucumber firmness was retained at the higher salt concentrations.

Measurement of Texture

Texture is an extremely important criterion of pickle quality. Consumers prefer a crisp, firm, hard textured pickle product. It is necessary that cucumber texture be evaluated by sensory methods, as well as objectively by texture measurement devices.

Hand operated fruit pressure testers have commonly been used for most of the objective textural evaluations of cucumbers and processed pickles. The best known hand-operated device is the Magness-Taylor fruit pressure tester (FPT) (Magness and Taylor, 1925). Textural quality can be objectively measured by FPT which provides a single overall value. Jones et al. (1954) applied the FPT to firmness measurement of salt stock pickles. Testing was accomplished by making a single puncture with the tester at the center of each cucumber of different varieties.

Jones and Etchells (1950) conducted sensory and FPT studies on no. 2 size fruit of 13 varieties in the raw, brined, fresh pack and sweet pickled products. Statistical analyses of FPT firmness values indicated significant differences among varieties within both raw and brined lots.

Bell et al. (1955) devised firmness rating scales for salt-stock pickles based on FPT values. The firmness ratings were as follows:

Pressure test	Firmness rating
18 lbs. and above	very firm
14 thr. 17 lbs.	firm
11 thr. 13 lbs.	inferior
5 thr. 10 lbs.	soft
4 lbs. and below	mushy

In his study, Bourne (1968) concluded that cucumber texture is affected by brining but textural quality is too complex to be analyzed definitively by an objective procedure providing only a single value.

While the Magness-Taylor FPT provides only a single value which is very useful, it is also felt that there is a need to research other objective methods providing analysis of the components. Pflug et al. (1960) modified the FPT method to a mechanically operated recording pressure tester (MRPT) so as to eliminate part of the human element from pressure testing and, at the same time, to provide a force displacement diagram for a better understanding of the behavior of the product during testing.

Nicholas (1960) reported measurable variations by individuals when firmness tests were made with a fruit pressure tester. Firmness measurements of several materials are shown to be different depending on the individual making the measurement. Individuals are shown to vary from time to time in their measurements of firmness of a single product. Comparisons of the variance of the force readings obtained by a MRPT showed discrepancies depending on the product tested.

Szczesniak and Bourne (1969), in reviewing objective firmness procedures, noted that while pressure or puncture methods had been assumed to be measuring firmness, there was little published evidence of attempts to correlate the objective data with sensory responses. Szczesniak et al. (1963) developed a Texture Profile Analysis (TPA) technique by which textural parameters were derived from force vs. distance curves plotted on the General Foods Texturometer (Friedman et al., 1963) during compression of a standardized food sample under prescribed conditions. The TPA parameters include hardness, cohesiveness, viscosity, elasticity, brittleness, adhesiveness, chewiness, and gumminess.

Breene et al. (1972) determined Instron TPA parameters of brittleness, cohesiveness, elasticity, gumminess, and chewiness to learn the nature and extent of textural differences in a wide range of cucumber stocks. They found significantly different mean values among varieties for all parameters. These workers suggested that textural quality might be adequately assessed by measuring one or more parameters of brittleness, hardness and total work expended in sample compression.

Jeon and Breene (1973) concluded from the highly significant positive correlations that the sensory panel and any of the instrumental methods, Instron, TPA and Magness-Taylor FPT, were measuring similar properties of cucumber texture. Since FPT showed positive correlations with sensory and Instron procedures its continued use for field purposes was recommended. However, in view of its low sensitivity and significant operator variability (Nicholas, 1960), its use in research for detecting small textural differences should be deemphasized.

Breene et al. (1973) designed a study to determine the relationship between Instron texture profile parameters of raw and brined cucumber fruit and to determine whether textural quality of raw fruit within a variety can be used to predict textural quality in the brined product of that variety. Their findings showed that varieties rating high in raw fruit textural quality usually produced brined fruit of high textural quality. Therefore firmness measured on green fruit may give a good indication of firmness that can be expected from salt-stock.

MATERIALS AND METHODS

5-Gallon Pail Pilot Brining Studies

Source and Analysis of Green-Stock Cucumbers

Cucumbers obtained from two sources were sorted to eliminate those possessing visible mold damage and injury. For the first year experiment, 12 5-gallon pails of size 3B mechanically harvested cucumbers were obtained from the Green Bay Foods plant in Eaton Rapids, Michigan (Summer 1978) and were brined as commercial-seeded stock. Twelve other pails contained hand harvested seedless cucumbers obtained from the Michigan State University horticulture experimental plots and were tested as control stock (Figure 2).

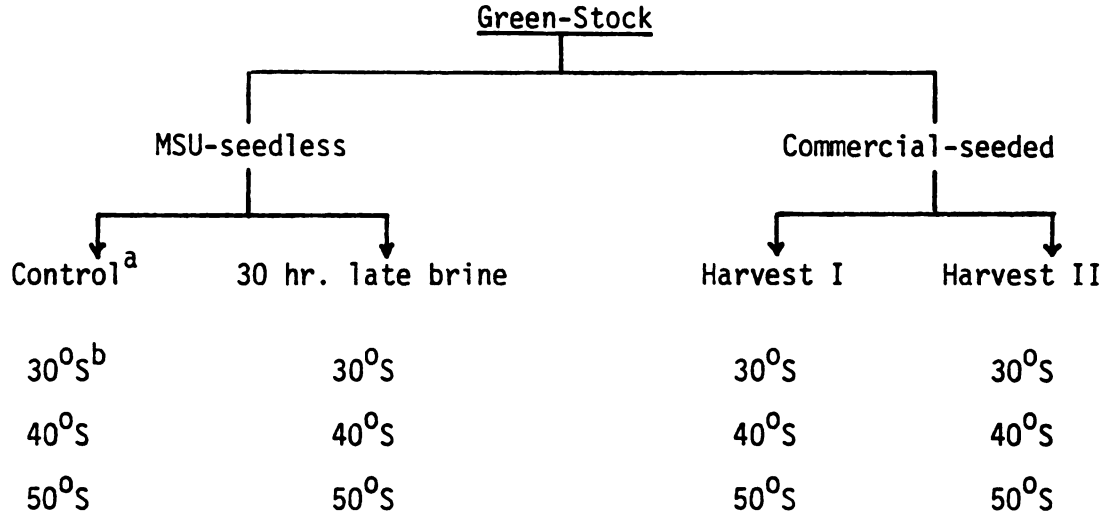
Moisture. Moisture was determined by A.O.A.C. methods (1970, 20.003b). Triplicate 25 g samples were weighted into tared aluminum moisture dishes and dried to a constant weight at 90°C for 24 hours in a force air oven. At the end of this drying time, the sample dishes were placed in a desiccator to cool before weighing. Moisture was expressed as percent weight lost during drying. The following equation was used:

$$\% \text{ Moisture} = \frac{\text{Weight of moisture lost (g)}}{\text{Weight of initial sample (g)}} \times 100$$

Total solids were expressed as percent solids and calculated as:

$$\% \text{ Solids} = \frac{\text{Weight of dried residue (g)}}{\text{Weight of initial sample (g)}} \times 100$$

Total Acidity, pH and Soluble Solids. A slurry was prepared for the determination of soluble solids, total acidity and pH. Cucumber slices



[a]Brined immediately after harvesting.

[b]Two replicate pails were maintained for each degree of salometer (S).

Figure 2. Treatment assignment for 5-gallon pail pilot brining studies.

(1" thick) totaling 100 g were obtained from 5 cucumbers and blended one minute at speed 70 with 200 ml distilled water in a glass jar fitted to a Waring blender base. Total acidity and soluble solid values were expressed on a fresh sample weight basis adjusted for slurry dilution.

Five ml of the slurry were titrated to an end point of 8.3 with 0.1 N NaOH using phenolphthlein as an indicator:

$$\% \text{ TA} = \frac{(\text{ml of NaOH})\ (\text{N of NaOH})\ (\text{meg wt of malic acid})}{\text{sample wt. g}} \times 100$$

Twenty ml of the blended slurry was filtered through #2 Whatman filter paper prior to measurement of refractive index for soluble solids. A Bausch and Lomb refractometer was used for the refractive index reading.

pH readings were made by a Beckman Zeromatic pH meter by inserting the pH electrode directly into 10 ml of the slurry.

Reducing Sugars. Reducing sugar was determined using a copper reduction method. One hundred g of green cucumber slices were mixed with 200 ml distilled water and blended in a Waring blender for 1 minute at speed 70. By use of the inverted pipet and mouth suction 25 g of this prepared slurry was transferred to a 100 ml volumetric flask. Nineteen ml of 80% ethanol were added and the flask was shaken. Two ml saturated lead acetate ($PbAc_2$) and 4 ml of saturated disodium phosphate (Na_2PO_4) were sequentially added. The flask was shaken after addition of each reagent. The flask contents were made to volume with 50% ethanol and held at room temperature for 30 minutes. At the end of this period, the extract was filtered through #1 Whatman filter paper.

Reducing sugar in the extract was determined by the Nelson-Somogyi Method (Jacobs). The percent transmittance of each sample was read at 600 nm; using a Bausch and Lomb Spectronic 70 spectrometer.

Brining Procedure and Brine Analysis

A pilot scale brining procedure was used for all brining studies. The system employed 5-gallon polyethylene pails designed to enable nitrogen gas purging to maintain anaerobic conditions during the fermentation (Costilow and Uebersax, 1978).

Cucumbers were brined with 40^{o} salometer brine (10.6% w/w NaCl) and acidified with 0.05% glacial acetic acid (1.9 ml glacial acetic acid per gallon of brine; 21.0 ml per 100 lb. brine). The 5-gallon polyethylene pails were filled with either 21.5 lb. of MSU-seedless or commercial-seeded cucumbers and covered with 19.5 to 20.0 lb. of prepared 40^{o} salometer brine. The morning after brining, 260 g dry salt were added to each pail to equilibrate at about 25^{o} salometer; the pails were purged 30 minutes with nitrogen. The pails were held for one week at 25 to 28^{o} salometer until the acidity registered about 0.6% calculated as lactic acid and then increased 3^{o}S per week. The addition of 85 g of dry salt 2 times per week to each pail resulted in an increase of 3^{o} salometer per week and this was continued until 30^{o}, 40^{o} and 50^{o} salometers were attained in the assigned pails.

The cucumbers were submerged in the brine by means of a perforated, 1/4 inch thick, flat, rigid polyethylene "false head" suppressed inside the fermentation pail about 1 in. below the brine surface by two 2" x 4" wooden blocks placed on top of the false head (Figure 3).

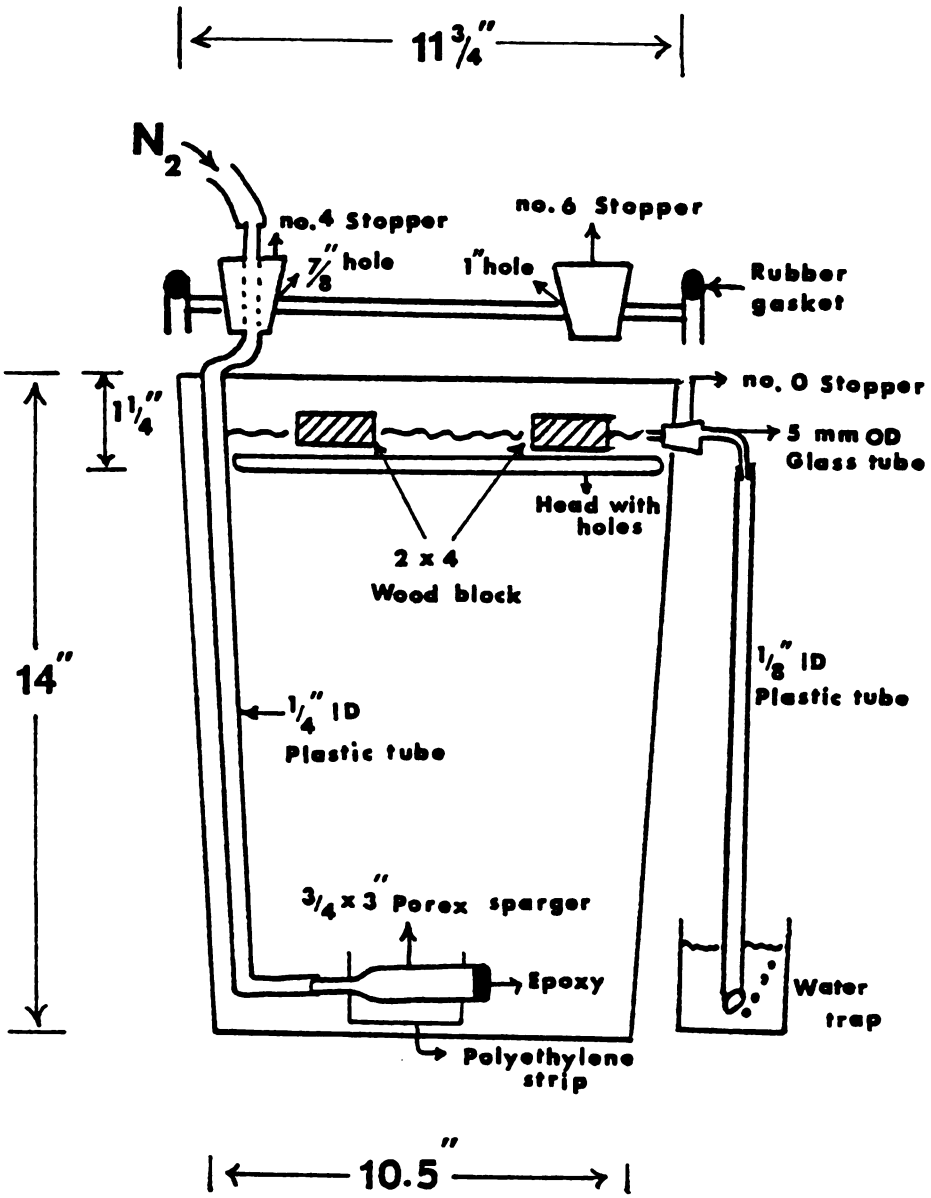


Figure 3. Design of pilot-scale brining pails. (Costilow and Uebersax 1978)

The gas diffusing spargers were prepared from ultra high molecular weight polyethylene tubes. They were cut into the proper length and sealed on one end with a polyethylene plug and on the other end, with a connecting adapter sized for 1/4" plastic tubing. Epoxy cement was used to seal these ends to assure a pressure tight seal.

Spargers were held in the bottom center of the pail using a sling cut from 3 mil flexible polyethylene film. The sling was heat sealed to the bottom center of the pail using a heat sealer for plastic or a small soldering iron. The center of this film was heat sealed to permit the sparger to be inserted through the large hole into the small one and then attached firmly in place by the 1/4" plastic tubing.

The 7 mm O.D. glass tubing used with the #4 rubber stopper for the gas entry port was bent at 90^{o} to prevent crimping of the tubing inside the pail and resultant restricted gas flow. The holes were uniformly cut with a drill press and tested to ensure a tight seal for all rubber stoppers.

The lower portion of the inner and outer flanges of the pail cover were notched to eliminate interference with the #0 rubber stopper used for the overflow tube.

Cucumbers were placed in the containers, covered with brine, and immediately purged with nitrogen. During the purging there was a steady stream of small bubbles into the water trap (approximately 20 ml/min). After purging 30 minutes, the nitrogen was shut off. If cucumbers were brined in the morning they were purged again for 15 minutes in the evening. A regular schedule of 15 minute purging in the morning and 15 minutes in the evening was done until CO_2 concentrations remained

very low (less than 13 mg CO_2/100 ml brine). Nitrogen purging followed all salt additions to aid in distributing the salt, as well as to establish anaerobic conditions.

Total Acidity. Total acidity was measured by the use of 5 ml brine samples titrated with 0.1 N NaOH, to a phenolphthalein end point. The acidity is expressed as grams of lactic acid per 100 ml of sample. Brine samples were taken daily until the acidity reached 0.6 to 0.7 percent as lactic acid.

pH. Brine pH was determined by using a Beckman Zeromatic pH meter. Readings were made by inserting the pH electrode directly into the brine sample.

Salometer. Brine salt concentration was determined by density. A salometer (Thomas Co., Philadelphia, Pennsylvania), having a range of 0 to 100^{o}S in 1^{o} divisions, was used for direct reading of degree of salt saturation. Three hundred ml of brine were placed in a graduated cylinder and the salometer inserted for reading. A reading of 100^{o}S indicates a saturated solution of sodium chloride in water, i.e. 26.395% salt.

Carbon Dioxide. Samples for CO_2 determination were taken twice daily before and after the nitrogen purging. Since CO_2 escapes from the brine when exposed to air, a closed sampling container such as a syringe was used. Five ml of brine were transferred to a vacutainer containing 0.2 ml 5 N NaOH by injecting through the rubber head. Because some CO_2 will be released into the head space of the container, the samples were left about half an hour to ensure maximum precipitation as calcium bicarbonate

before testing. One ml of sample is placed in the CO_2 assay vial and a rubber gromet is inserted. With a tuberculin syringe, 0.2 ml 50% lactic acid was injected into the vial. The vial was placed on a vortex shaker until the maximum expansion due to the release of the CO_2 was achieved. The greater the concentration of CO_2 the longer the shaking time. The number of units the plunger had risen was read. Before running brine samples, a one ml background standard (0.2 ml 5 N NaOH in 5 ml boiled H_2O) and a one ml CO_2 standard (100 mg/ml) were tested using the described method. The amoung of CO_2 present was expressed as mg CO_2 per 100 ml brine;

$$\text{mg } CO_2/100 \text{ ml} = \frac{CO_2 \text{ standard reading} - \text{Background reading}}{100} \times \text{Sample reading}$$

Salt-Stock Pickle Analysis

Ash and Mineral Composition. Total ash was determined using a variation of the A.O.A.C. (1970, 29.012) method. Duplicate 5 g samples were weighed into tared 50-ml (51 x 43 mm) Coors porcelain crucibles and dried at 100°C for 24 hours. Dried samples were pre-ashed over a Fisher burner. Crucibles were then placed in a muffle furnace and heated at 550°C until a uniform white ash was obtained (24 hours). Ashed crucibles were held in a desiccator to cool before weighing. Percent ash was calculated as a function of the noncombustible material on a fresh weight basis, using the following equation.

$$\% \text{ Ash} = \frac{\text{Weight of ash residue (g)}}{\text{Weight of initial sample (g)}} \times 100$$

Calcium and magnesium were determined using atomic absorption spectroscopy. The ash obtained from 5 g of pickle sample was dissolved in 10 ml 6 N nitric acid and cooled prior to filtering into a 100 ml volumetric flask and made to volume with deionized water.

Using a standard curve, minerals were quantitified by their characteristic emission spectra at specific wavelengths (Ca, 422.7 nm; Mg, 285.2 nm). Samples were run in duplicate and were expressed as either percent or ppm on a fresh weight basis.

Texture. Green and salt-stock cucumbers were prepared for texture evaluation using the Instfon Universal Testing Machine (Model TTBM). Maximum length and width measurements of each cucumber were recorded before cutting. Two cross-sectional pieces (1" thick) were cut from each of 15 cucumbers from each treatment pail. One cross-sectional piece was cut from the stem (S) end and the other from the blossom (B) end. Those pieces were used for crushing measurement. Four 3/16" slices were cut from the area between the ends for slice punching (Figure 4). Peak force was calculated and expressed in kg. Crosshead speed was 10 cm; chart speed was 30 cm, full-scale setting was 1 kg for slice punching and 20 kg for piece crushing.

Brine stock firmness was measured with a Magness-Taylor fruit pressure tester (FPT), 8 mm (5/16") tip (Bell and Etchells, 1961). For this study, each pressure test value represented the average of 20 pickles, each pickle punctured once through the side wall midway between the stem and blossom ends. Readings were expressed in pounds force required to pierce the surface.

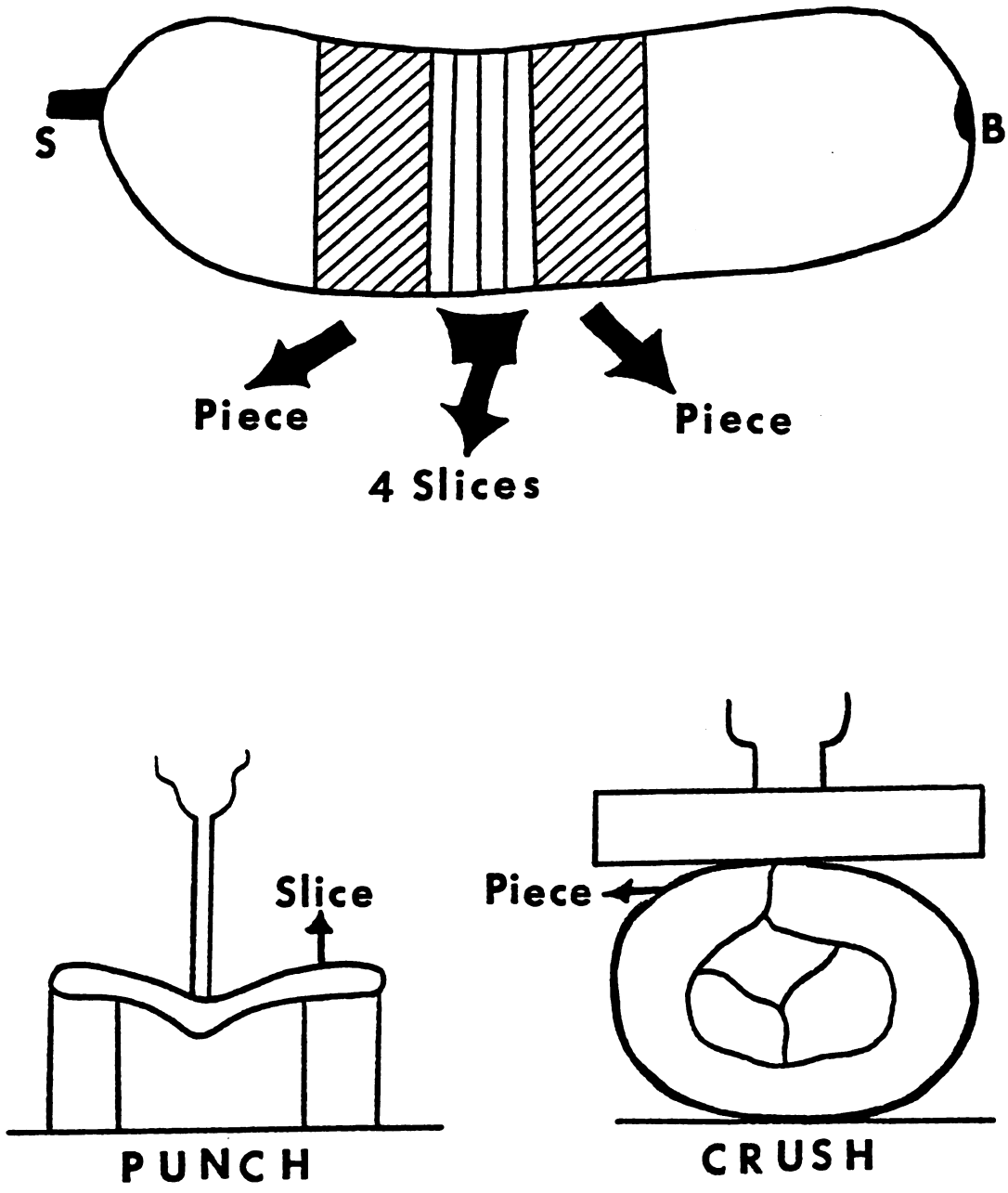


Figure 4. Cucumber sample cut and placement in Instron for texture measurement.

Visual Evaluation. Brine stock was prepared and pickles were evaluated visually for bloater-type defects. Pickles were cut longitudinally and the damage was categorized according to type (balloon, lens, honeycomb) as suggested earlier by Etchells et al. (1974). In this study damage was reported as percentage of the cucumbers affected by each type of defect.

1-Gallon Jar Pilot Brining Studies

Treatment Assignment

Cucumbers for the 1-gallon jar pilot brining studies were obtained from Green Bay Foods plant in Eaton Rapids, Michigan (Summer 1979). Pectinolytic enzyme activity was studied in 32 1-gallon jars as outlined in Figure 5. Part I of this study was designed to evaluate the effect of the addition of previously fermented salt stock on bloater defects and soft center development. Soft pickles and the associated soft brine and firm pickles and the associated firm brine substituted into fresh cucumber fermentations. Potassium sorbate was added to control and those fermented containing soft pickles and soft brine. Part II of these experiments included cucumbers brined to different final end point salt concentrations, ranging from 25^{o} to 50^{o} salometer with 5 degree intervals.

Brining Procedure and Brine Analysis

Cucumbers were weighted and packed into 1-gallon jars, which were filled with 40^{o} salometer brine. The jars were covered first with a polyvinyl film and then with cheesecloth. Melted paraffin was used to seal the jars (Figure 6). The number of cucumbers per jar was held as nearly constant as possible. For size no. 3B's, 13 cucumbers were packed

Part I Control (C)[ab]

C + 25% w/w soft brine (SB)

C + 25% w/w soft pickle (SP)

C + 25% w/w firm pickle inside

C + 25% w/w firm pickle outside

C + 25% w/w soft pickle inside

C + 25% w/w soft pickle outside

C + 0.1% sorbate (S)

C + 25% soft brine + sorbate (SB + S)

C + 25% soft pickle + sorbate (SP + S)

Part II Control (C)

C + 25° Salometer

C + 30° Salometer

C + 35° Salometer

C + 40° Salometer

C + 45° Salometer

C + 50° Salometer

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[a]Control contains green stock cucumbers and 40°S fresh brine.

[b]Two replicates were provided for each treatment.

Figure 5. Treatment assignment for 1-gallon jar pilot brining studies.

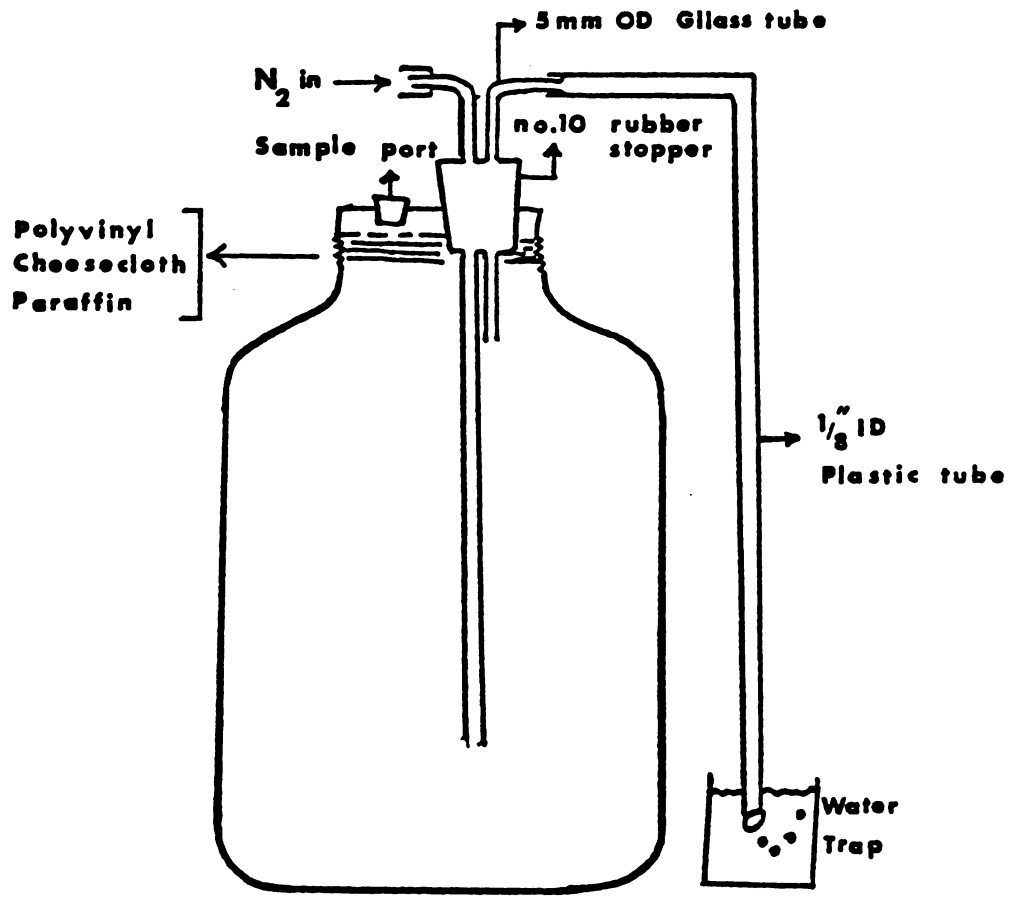

Figure 6. The assembly of fermentation jar for pectionolytic enzyme activity study.

per jar. Fermentations were nitrogen purged to remove excessive brine CO_2. Brine samples were removed at specified intervals through a sample port sealed with a rubber stopper. Nitrogen purging was initiated immediately after each sample was removed to reestablish anaerobic conditions.

Pectinolytic Activity. Cucumbers were kept in brine for 26 days before evaluation for characteristic defects and soft center development. During the fermentation, enzymatic activity of the brine was determined at 5 day intervals for each treatment. Enzymatic activity measurement was scheduled as follows:

Test number	Age of fermentation (days)
1	5
2	10
3	15
4	20
5	25

Pectinolytic enzyme activity was determined by the method suggested by Bell et al. (1955). According to this method the brine samples were reacted with pectate solution. The flow time was measured in Ostwald-Fenske viscosity pipets containing pectate solution and dialyzed sample. The flow time in seconds for each pectate-sample was recorded initially (A), at the 20-hour incubation period (B_{20}) and at the 44-hour incubation period (B_{44}). Softening activity was expressed as loss in viscosity of the pectate-sample. The conversions were made from loss in viscosity (%) values to pectinolytic activity units (Bell et al., 1955).

Total Acidity, pH, and Salometer. These three parameters were determined during the fermentation by the same methods described in the 5-gallon pail pilot brining studies.

Salt-Stock Texture and Visual Evaluation

Salt-stock firmness was measured with a Magness-Taylor fruit pressure tester according to the procedure outlined in the 5-gallon pail pilot brining studies. Each pressure test value represents the measurement of 10 salt-stock cucumbers.

Salt-stock cucumbers were visually evaluated for bloater-type defects and soft center development as suggested by Etchells et al. (1974).

Statistical Analysis

The multivariate analysis of variance and observed means and standard deviations were calculated according to the methods outlined by Sokal and Rohlf (1969) using a Texas Instrument Programmable 59 calculator.

Mean squares from the analysis of variance were reported with significant probability levels of 5% (*), 1% (**) and 0.1% (***).

Regression equations and coefficient correlations were calculated from observed data using a Canon Canolo F.20 P calculator.

RESULTS AND DISCUSSION

5-Gallon Pail Pilot Brining Studies

Green-Stock Cucumbers

Mean values and standard deviations of chemical composition of green-stock cucumbers including soluble solids, total solids, total acidity, pH and Instron force (kg) values are presented in Table 1. The analysis of variance (ANOVA) for those data is summarized in Table 2. Except for reducing sugar, there is no significant difference in cucumber composition due to the treatments and sources of cucumbers. Reducing sugar content ranged between 1.80 and 1.82% for MSU-seedless cucumbers; 2.18 and 2.20% for commercial-seeded stock. Holding for 30 hours at 30°C did not affect the content of reducing sugar. Similar results were obtained by McCombs et al. (1976). Their study indicated that the storage period (3 days at 16°C) produced no differences in reducing sugar.

The sugar content of cucumbers is of great importance to the pickling cucumber industry since it serves as substrate for microorganisms during fermentation. Sugar remaining after the primary fermentation serves as an energy source for secondary fermentation. This secondary fermentation causes CO_2 production and bloater damage. In this study seedless cucumbers possessed lower reducing sugar content than did the seeded cucumbers. Theoretically, less bloater damage is expected with seedless cucumber salt-stock than seeded cucumber salt-stock.

Center slice punching and side crushing force values of 15 fresh cucumbers for each treatment were measured by the Instron. Slice punching

Table 1. Chemical composition and Instron force (kg) values of green-stock cucumbers.[1]

Treatment	Soluble Solids °B	Total Solids %	Total Acidity %	pH	Reducing Sugar %	Bloom 1	Center Punch Slice Location 2	3	Stem 4	Side Crush Piece Location Bloom	Stem
MSU											
Control	3.06±0.08	5.07±0.23	0.026±0.0	5.5±0.0	1.80±0.0	0.19±0.03	0.20±0.04	0.19±0.03	0.20±0.03	6.1±0.77	6.3±2.5
30 hour	3.4 ±0.20	5.07±0.23	0.028±0.0	5.5±0.0	1.82±0.01	0.20±0.04	0.19±0.017	0.18±0.04	0.16±0.02	4.7±0.7	4.9±0.9
Commercial											
Harvest I	3.3 ±0.0	5.3 ±0.46	0.029±0.01	5.0±0.0	2.20±0.0	0.16±0.01	0.15±0.04	0.13±0.04	0.15±0.05	3.1±0.36	3.4±0.21
Harvest II	3.0 ±0.0	5.07±0.23	0.030±0.01	5.0±0.0	2.18±0.0	0.13±0.02	0.12±0.02	0.10±0.01	0.11±0.04	3.8±1.59	3.6±0.84

[1]Mean values and standard deviations
Chemical analysis n = 3 replicate samples
Instron force study n = 15 determination; 3 replicate groups of 5 cucumbers

Table 2. Analysis of variance of chemical composition and Instron force (kg) values of green-stock cucumbers

Source of Variance	df	MEAN SQUARES										
		Soluble Solids	Total Solids	Total Acidity	pH	Reducing Sugar	Bloom 1	Center Punch Slice Location 2	Center Punch Slice Location 3	Stem 4	Side Crush Piece Location Bloom	Side Crush Piece Location Stem
Location											**	**
MSU vs. Commer.	1	0.02	0.10	1.3×10^{-5}	0.75	5.34*	0.01	5.7×10^{-3}	1.7×10^{-2}	1.2×10^{-2}	11.9	13.0
Treatment	1	0.3	0.10	0.0	0.0	3.40	0.00	0.0034	0.001	2.1×10^{-3}	0.3	0.9
Location vs. Treatment	1	0.0	0.0	0.0	0.0	1.2	0.1×10^{-3}	0.00	0.6×10^{-3}	0.3×10^{-3}	3.1	1.68
Error	8	0.01	0.13	2×10^{-3}	0.0	0.02	0.01	0.9×10^{-3}	0.9×10^{-3}	0.1×10^{-2}	1.29	2.03

*Significant at $p \leq 0.05$

**Significant at $p \leq 0.01$

force values showed no significant differences between treatments and green-stock sources (Figure 7). In this study 3/16" slice thickness was used. This thickness might not be adequate to measure the slice punching force value. It could be advisable to increase the slice thickness to 1/4" for improved uniformity in punch force resistance.

Side crushing force values for bloom and stem pieces from MSU-seedless cucumbers were significantly ($p \leq 0.05$) higher than commercial-seeded cucumbers (Figure 8). One-way analysis of variance (Table 3) showed that cucumbers held for 30 hours at $30^{o}C$ had lower crushing force values than the cucumbers measured immediately after harvesting. Holding of cucumbers for a specified period decreases the relative firmness of green-stock cucumbers.

Brine Analysis

All 24 pails involved in this study were allowed to undergo fermentation by the natural microflora. During the natural fermentation, nitrogen purging was applied to control the CO_2 level in the brine. Chemical changes during the fermentation of cucumbers are illustrated in Figure 9. All pails fermented normally reached 0.6% acidity (as lactic acid) or slightly higher or lower within 16 days. The brine pH dropped from 5.5 to 3.0 within 14 days of fermentation. The brine equilibrated at 25-26^{o} salometer within 6 days. Specific salt concentrations (30^{o}, 40^{o}, and $50^{o}S$) were attained in pails at different times by addition of dry salt during the fermentation (Figure 10).

Carbon dioxide concentration (mg/100 ml) was measured prior to purging and following the 15 minute purge. Purging with nitrogen gas

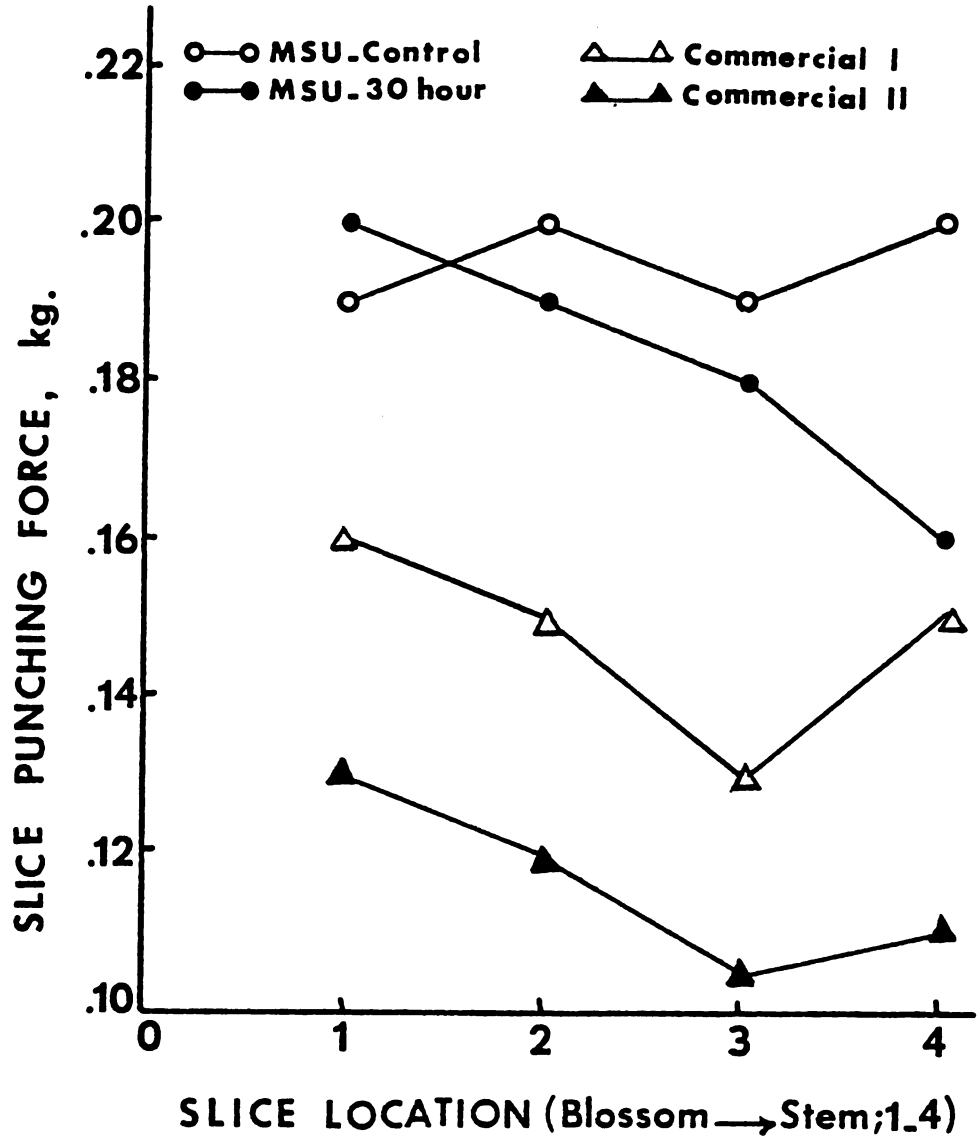

Figure 7. Slice punching force values vs. slice location of green-stock cucumbers.

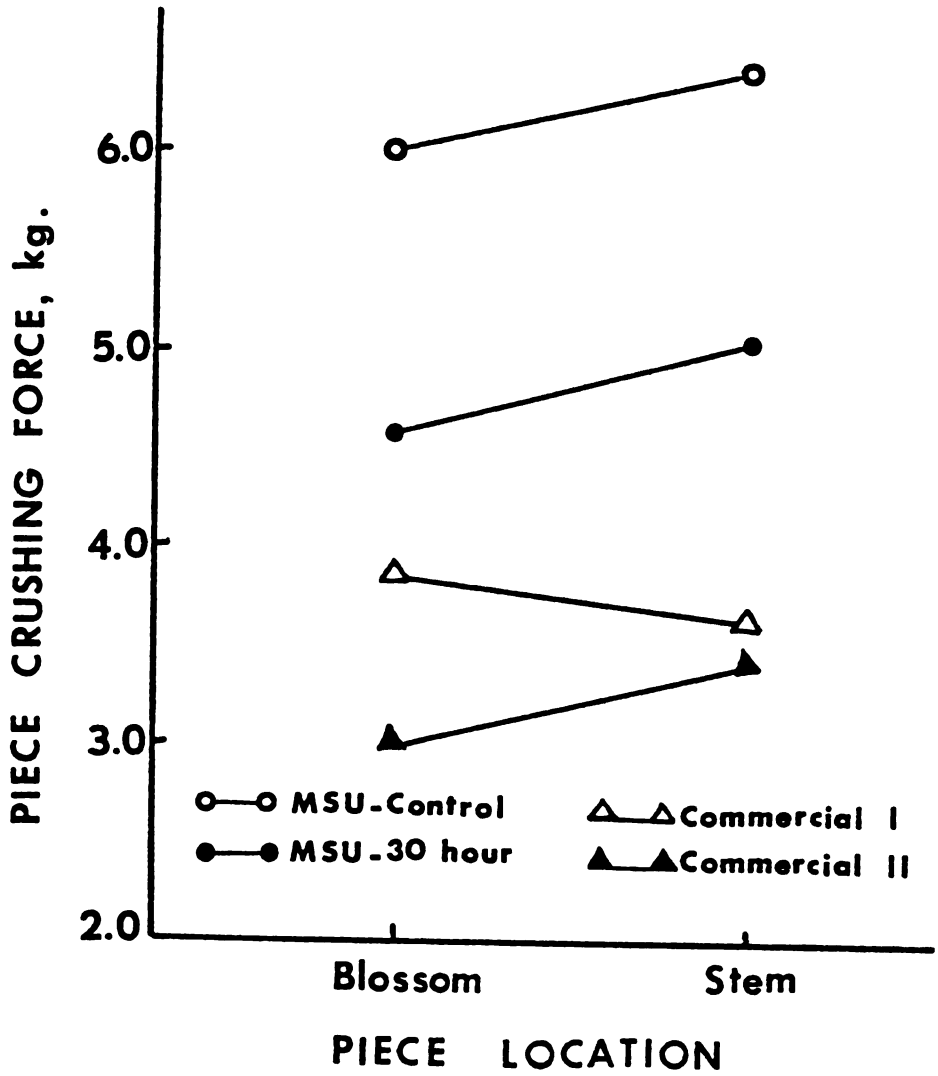

Figure 8. Piece crushing force values vs. piece location of green-stock cucumbers.

Table 3. One-way analysis of variance of Instron force (kg) values of green-stock cucumbers.

		MEAN SQUARES											
		MSU-Control--Seedless						Commercial--Seeded					
		Center Punching				Side Crushing		Center Punching				Side Crushing	
Source of Variance	df	Bloom → Stem 1	2	3	4	Bloom	Stem	Bloom → Stem 1	2	3	4	1	2
Between Treatments	1	$1.5x10^{-4}$	$2.4x10^{-3}$	$0.3x10^{-4}$	$0.6x10^{-3}$	7.81*	8.20*	$1.1x10^{-3}$	$0.1x10^{-2}$	$0.2x10^{-3}$	$0.2x10^{-2}$	0.66	0.05
Error Within Treatment	4	$1.05x10^{-3}$	$7.5x10^{-4}$	$9.6x10^{-4}$	$0.7x10^{-3}$	1.25	3.68	$0.3x10^{-3}$	$0.8x10^{-3}$	$0.9x10^{-3}$	$1.6x10^{-3}$	1.34	0.36

*Significant at $p \leq 0.05$

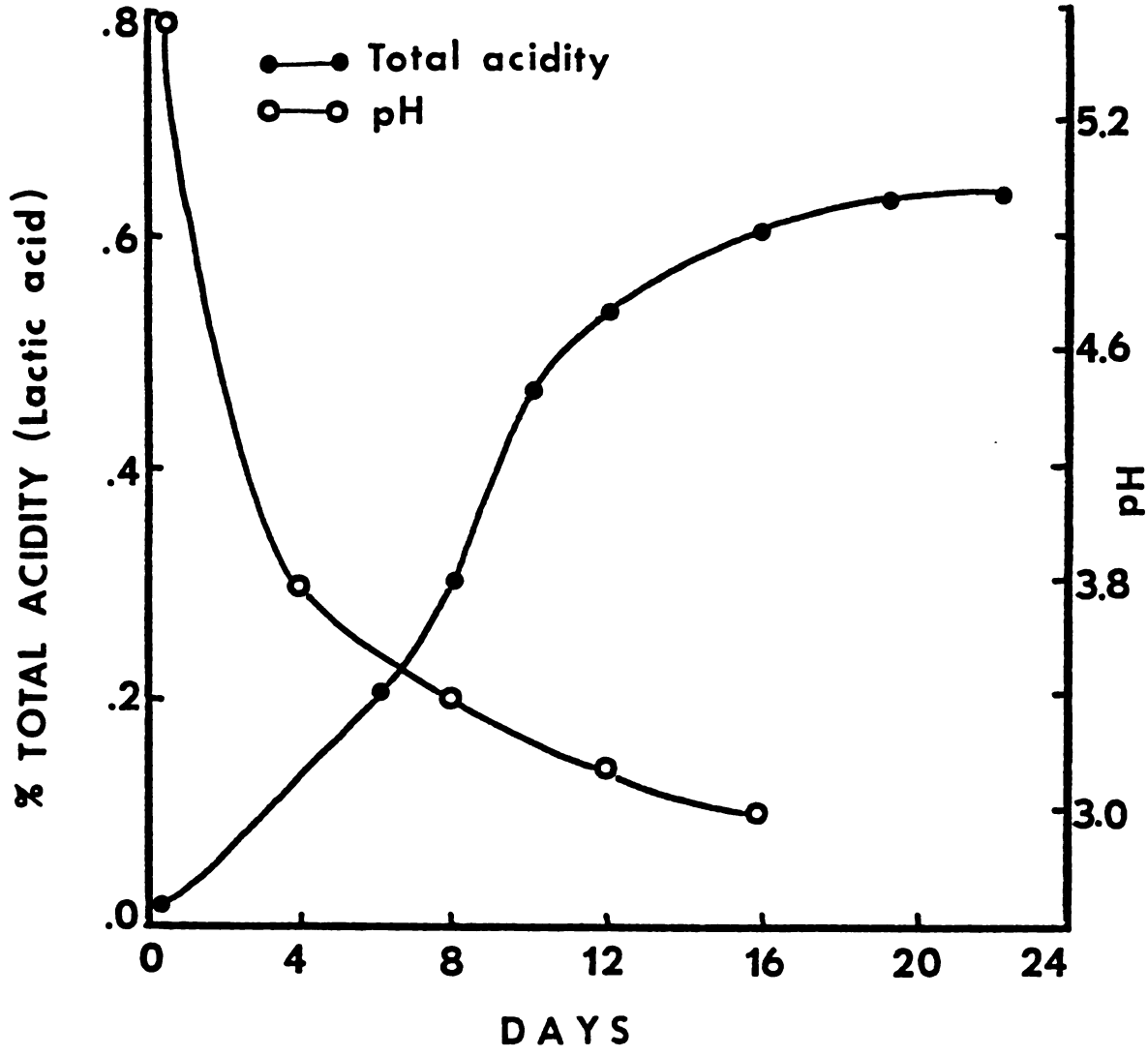

Figure 9. Relationship of changes in titratable brine acidity (as lactic acid) and pH during fermentation.

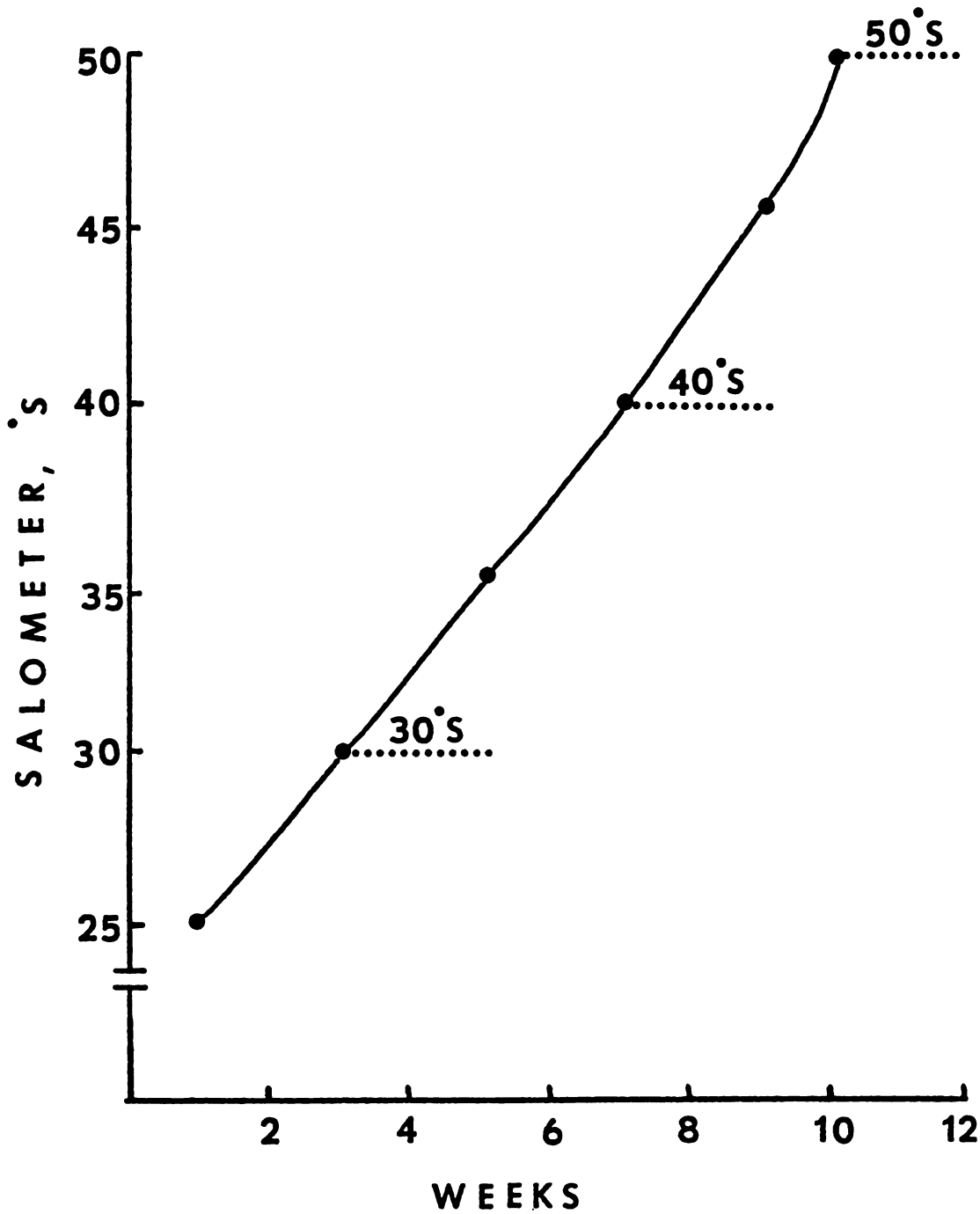

Figure 10. Attainment of brine salinity (30^{o}, 40^{o} and 50^{o}S in pails during fermentation of cucumbers.

was found to be effective in maintaining relatively low CO_2 levels (Figure 11). The data obtained supported the study by Costilow and Bedford (1977) such that it was possible to greatly reduce the build-up of CO_2 in salt-stock pickle brines undergoing natural fermentation. Table 4 shows the brine CO_2 concentration during fermentation of MSU-seedless and commercial-seeded cucumbers. Brine in MSU-30 hour late brined cucumbers retained the highest concentration (22.6 mg/100 ml) of CO_2 during the active period of fermentation. It is apparent that the holding of cucumbers before brining increased the brine CO_2 concentration. This may be attributed to the increased respiration rate of the cucumber, increased microflora population or possibly tissue damage occurring during the 30 hour holding period at $30^{o}C$.

The CO_2 level in brine of seedless cucumbers stabilized in 12 days, but it required 20 days to stabilize for commercial-seeded cucumbers (Figure 12).

The CO_2 concentrations obtained in this study indicated that the concentrations of CO_2 in brine were high during the first six days after brining. Therefore, it is very important to start purging immediately after covering the cucumbers with brine. Fleming et al. (1975) observed that the percent of pickles with bloater damage from controlled fermentations was at a maximum 2 days after brining.

Salt-Stock Evaluation

Visual Evaluation. Evaluation of brine stock for bloater damage was done 3 months after brining. Forty brined cucumbers for each treatment were cut longitudinally and examined. Subjective evaluations of bloater

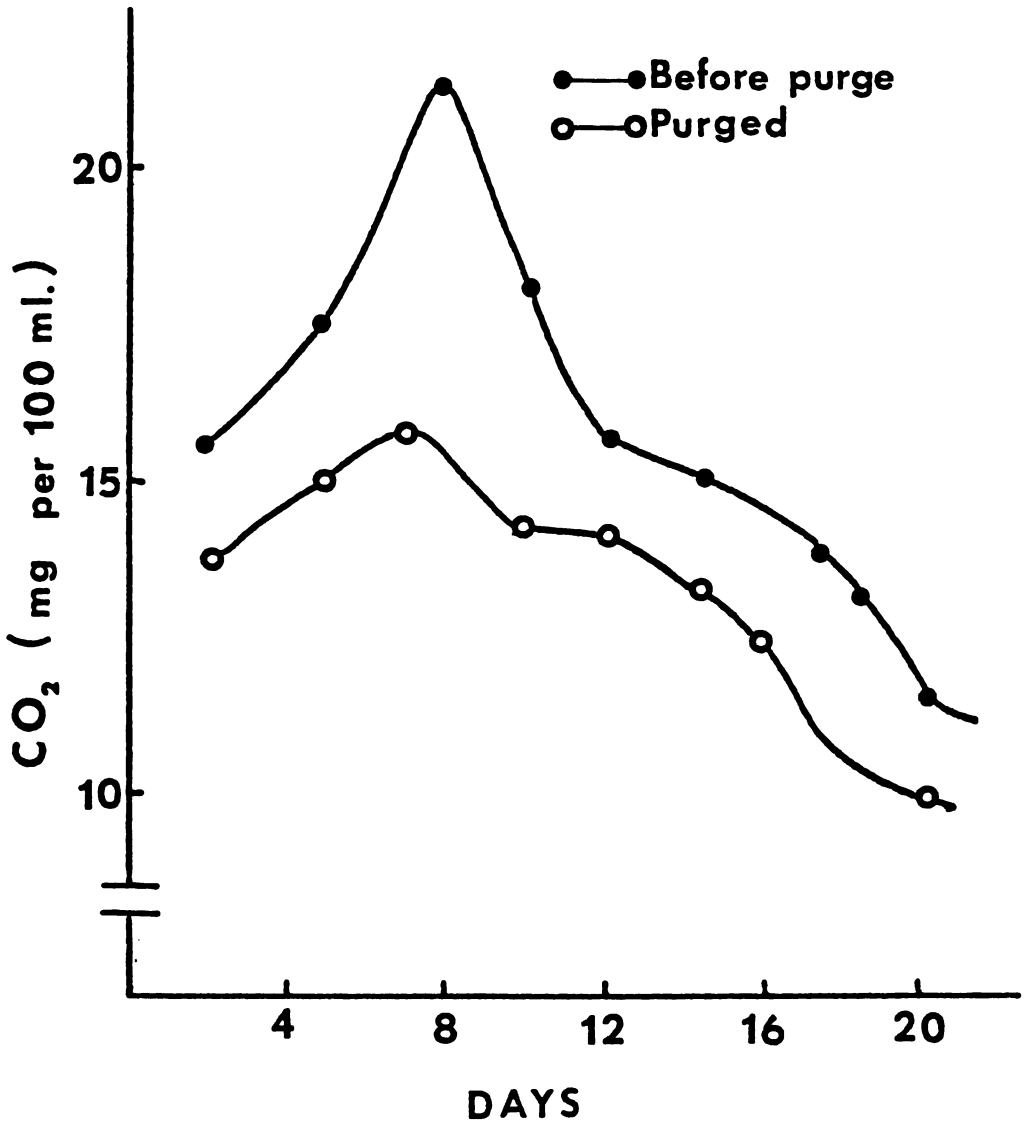

Figure 11. Effect of nitrogen purging on reduction of CO_2 concentration in brine. (Data obtained from MSU control stock.)

Table 4. Brine CO_2 concentration (mg per 100 ml) of cucumbers during fermentation.[1]

Fermentation Days	MSU-seedless		Commercial-seeded	
	Control	30 hr. late	Harvest I	Harvest II
1	19.29∓1.23	18.7∓1.08	16.14∓0.65	18.77∓0.62
2	17.53∓0.31	17.77∓0.53	--	--
3	18.7∓1.76	22.6∓0.74	--	--
4	16.7∓0.74	18.7∓0.31	--	--
5	--	--	18.56∓0.55	17.6∓0.93
6	--	--	19.1∓0.11	18.32∓1.47
7	16.95∓1.06	15.26∓0.85	19.83∓2.31	16.5∓1.96
8	14.81∓1.24	13.27∓0.52	17.1∓1.14	14.56∓0.1
9	14.59∓1.35	12.88∓0.38	--	--
10	12.55∓0.14	12.31∓0.04	--	--
12	12.15∓0.00	11.68∓0.03	--	--
14	--	--	13.7∓0.91	14.3∓0.73
15	--	--	12.45∓0.31	13.77∓0.53
18	--	--	12.15∓0.51	11.85∓0.11
20	--	--	12.58∓0.49	12.4∓0.00

[1]Mean values and standard deviations, n=2 replicate pails

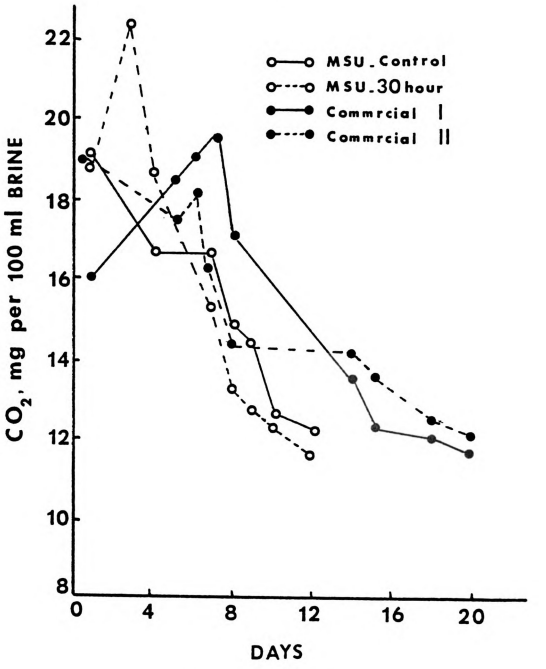

Figure 12. Concentrations of dissolved CO_2 in MSU-seedless and commercial-seeded cucumber brines during fermentation.

damage were reported as a percentage of cucumbers showing characteristic bloater defects (balloon, lens and honeycomb) and soft center development.

Table 5 presents the percentage of salt-stock with various bloater-type defects in MSU and commercial stock at three different salometers (30^{o}, 40^{o}, and 50^{o}S). The differences in the percent of total defects between MSU-control and MSU-30 hour late brine pails were dramatic. Cucumbers held for 30 hours at 30^{o}C before brining showed the most defects and the highest CO_2 levels among all the pails. Some of the pickles in these pails were disintegrated and could not be evaluated. Salt concentrations did not affect the percentage of bloater defects. It was found that all three salt concentrations had nearly the same percent of defects. Purging also failed to reduce the frequency of the defects in these pails. It was apparent that the occurrence of bloater-type defects was increased by holding the cucumbers in a relatively high temperature before brining. It appears probable that many cucumbers became soft and mature at the time of holding and that many converted to severe-type bloaters (Figure 13).

The results obtained in the present study indicate that the percent of pickles with bloater damage from MSU-30 hour late brined cucumbers was high. It cannot be recommended to the pickle industry to hold the cucumbers at relatively high temperatures for a long time before brining.

MSU-control cucumbers showed the least number of bloater-type defects. The total defect at 30^{o} salometer was slightly lower than at the 40^{o}S and 50^{o}S. The balloon and honeycombs are the most unacceptable types of defects (Costilow and Bedford, 1977). As indicated in Table 5, the sum of those two defects was 13, 18 and 28% in 30^{o}, 40^{o} and 50^{o} salometers, respectively.

Table 5. Effects of various treatments on the percentage of pickles with various defects and maximum brine CO_2 level.

Treatment	Bloater Damage[1]					Brine Analysis
	Balloon %	Lens %	Honeycomb %	Soft Center %	Total %	Max CO_2 mg/100ml
30^oS						
MSU-Control	10	8	3	0	21	20.68
MSU-30 hour	38	10	43	2	93	22.50
Comm. Harvest I	20	12	42	6	80	21.08
Comm. Harvest II	20	12	37	4	73	19.14
40^oS						
MSU-Control	15	14	3	0	32	18.92
MSU-30 hour	40	0	40	7	87	21.83
Comm. Harvest I	25	5	37	6	73	18.80
Comm. Harvest II	32	2	30	0	64	18.48
50^oS						
MSU-Control	22	0	6	2	30	18.92
MSU-30 hour	38	0	28	15	81	28.40
Comm. Harvest I	30	10	10	5	55	20.70
Comm. Harvest II	27	0	25	2	54	19.60

[1] n=40 cucumbers

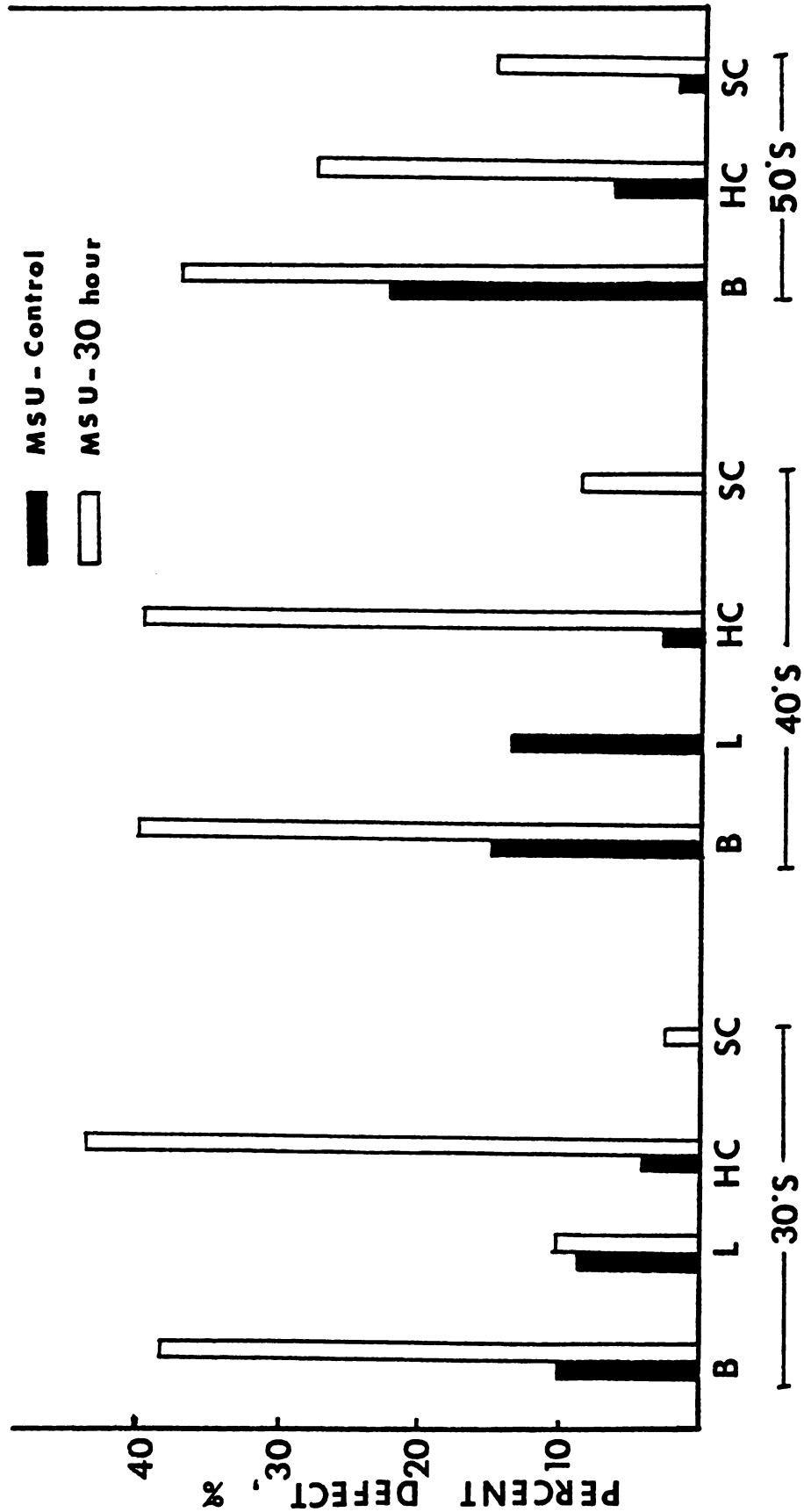

Figure 13. Percent salt-stock damage by defect class (Balloon, B; Lens, L; Honeycomb, HC; and Soft center, SC) for MSU stock brined immediately and after 30 hours at 30°C to 30°, 40° and 50° final degrees salometer.

Salt concentration was found to be effective in controlling bloater-type defects of commercial cucumbers. Better salt-stock was obtained as the salt concentration was increased. The total defects for commercial Harvest I cucumbers were 80, 73 and 55% in 30^{o}, 40^{o} and 50^{o} salometers, respectively (Figure 14). Surface growth was observed in 30^{o} and 40^{o} salometer containers but not in 50^{o} salometer pails. Residual sugars in such instances were fermented by subsurface yeasts with resulting bloater formation. According to Etchells (1950), brining procedures at commercial plants which use high initial salt concentrations were reported to favor large populations of fermentative yeast species and to be chiefly responsible for the bloater formation. In this study, the 50^{o} salometer was attained after the 0.6% acidity (lactic acid) and pH 3.0 were maintained.

As shown in Figure 15, serious bloater damage occurred in commercial-seeded cucumbers and not in the MSU-seedless stock. This could, perhaps be explained as follows: seedless cucumbers are more vigorous and longer lived due to the absence of seeds which presumably cause aging and other senescence processes (Baker et al., 1973). Therefore it is obvious that salt-stock was improved in appearance and fewer defects occurred by the use of seedless rather than seeded cucumber fruit. The method of harvesting was probably the second factor that affected the quality of salt-stock in this study. As it is reported by Garte and Weichman (1974), cucumbers harvested by machine have a 6 to 20% higher rate of respiration than those harvested by hand. Consequently, mechanical harvesting of commercial cucumbers caused higher mass losses over hand harvested MSU-cucumbers in salt-stock.

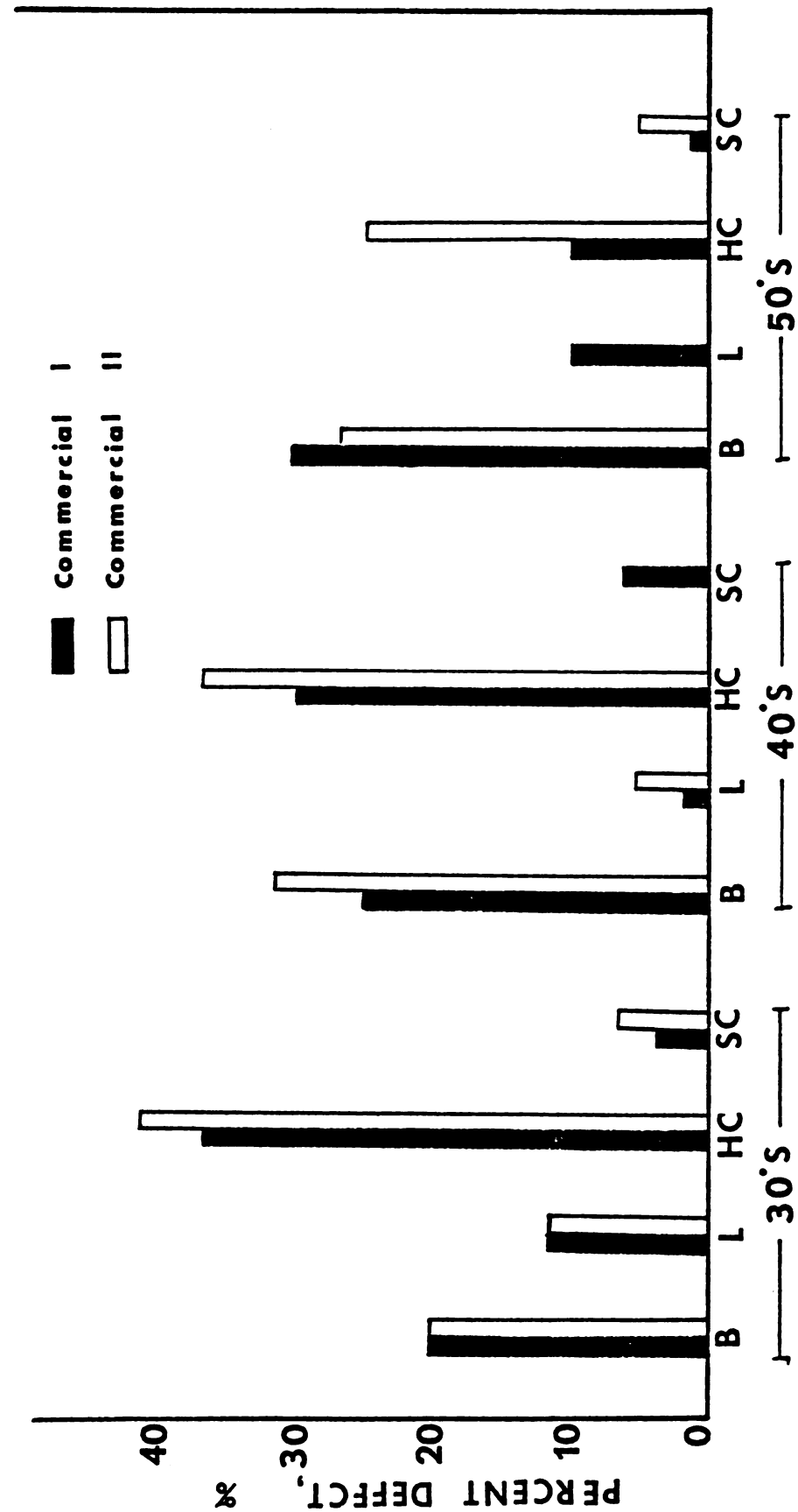

Figure 14. Percent salt-stock damage by defect class (Balloon, B; Lens, L; Honeycomb, HC; and Soft center, SC) for two harvest times of commercial stock brined to 30^0, 40^0 and 50^0 final degrees salometer.

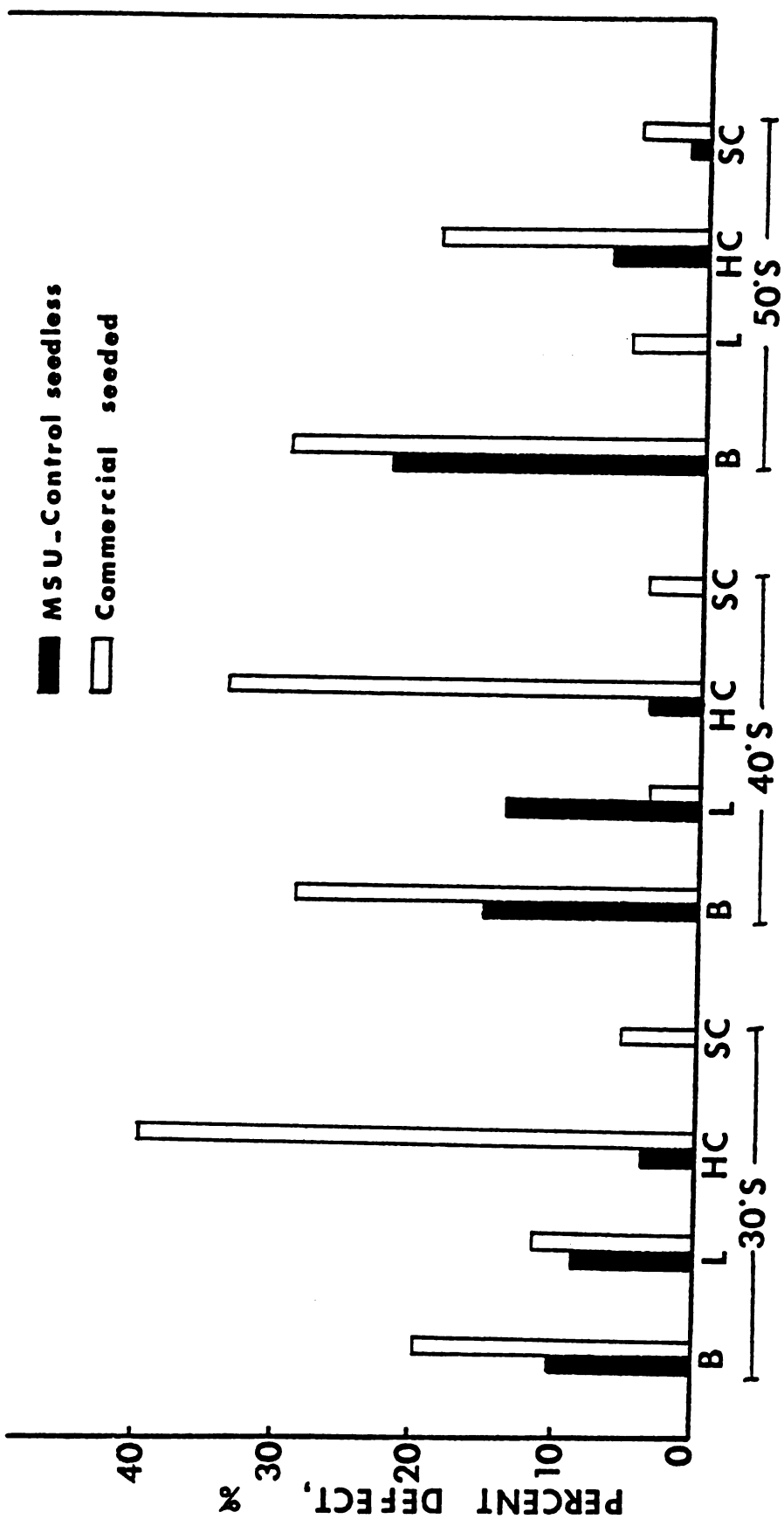

Figure 15. Comparison of percent salt stock damage by defect class (Balloon, B; Lens, L; Honeycomb, HC; Soft center, SC) for MSU-control seedless and commercial-seeded at 30^{o}, 40^{o} and 50^{o} final degrees salometer.

Generally, the external and internal color of the salt-stock cucumbers appeared to be a normal color, light green. The cucumbers having advanced balloon-type bloating were dry inside and a permanent cavity was present due to the tissue having been pressed toward the skin. Cucumbers were still moist inside when they had slight or moderate bloater-type defects.

Texture Measurement by Instron. Commercial salt-stock cucumbers were too damaged for Instron punching and crushing evaluation. The hollows in balloon-type bloating made it impossible to work with those cucumbers. At the time the commercial cucumbers were brined, they were free of any visual evaluation of green-stock appearance and firmness were poor indicators of the quality of salt-stock cucumbers. It is advisable that when field production is greater than plant capacity or when the field and processing plant are far apart, green-stock cucumbers should be stored in regular or controlled refrigerated atmosphere.

The mean values and standard deviations of Instron punching and crushing force values of MSU salt-stock cucumbers are given in Table 6. Mean values are based on 15 replicates of salt-stock cucumbers. Cucumbers brined after a 30-hour holding period and kept in 50^{o}S were found to be of poor condition for punching and crushing studies.

The ANOVA (Table 7) showed that slice punching force values did not differ significantly between the slice locations from bloom end to stem end. However, salt concentrations affected the force values. It was demonstrated that increasingly higher salt concentrations gave correspondingly higher force values for MSU-control stock.

Table 6. The mean values and standard deviations of Instron punching and crushing force (kg) values of MSU-seedless salt-stock.[1]

Treatment	Slice Location: Bloom → Stem 1	2	3	4	Piece Location: Bloom	Stem
MSU-Control						
30°S	0.12±0.03	0.15±0.02	0.15±0.01	0.17±0.03	3.1±0.9	3.8±0.5
40°S	0.20±0.02	0.17±0.03	0.19±0.01	0.18±0.01	3.6±0.4	4.1±0.3
50°S	0.21±0.01	0.22±0.01	0.20±0.03	0.21±0.02	3.8±0.2	4.4±0.7
MSU-30 hour						
30°S	0.11±0.01	0.10±0.02	0.09±0.02	0.12±0.00	2.5±0.3	3.2±0.3
40°S	0.10±0.02	0.12±0.04	0.14±0.01	0.13±0.01	3.0 0.5	3.4±0.2
50°S[2]	--	--	--	--	--	--

[1] n=15 determinations; 3 replicate groups of 5 cucumbers.

[2] Samples were not suitable for texture measurement due to excessive softening.

Table 7. Analysis of variance of Instron force (kg) values of MSU-seedless salt-stock cucumbers.

Source of Variation	df	Punching Mean Squares
Treatment(A) (holding time)	1	0.69
Slice loc.(B)	3	0.01
Salometer(C)	2	0.81
A x B	3	0.00
A x C	2	0.03
B x C	6	0.00
A x B x C	6	0.00

Source of Variation	df	Crushing Mean Squares
Treatment(A) (holding time)	1	19.54*
Piece loc.(B)	1	18.55*
Salometer(C)	2	20.04*
A x B	1	9.54
A x C	2	21.03*
B x C	2	22.13*
A x B x C	2	2.79

*Significant at $p \leq 0.05$

Piece crushing force values differed significantly ($p \leq 0.05$) with MSU-control and MSU-30 hour late brined stock. Higher force values were obtained with control salt-stock cucumbers. The 30-hour holding period adversely affected the salt-stock firmness. Analysis of variance indicated significant differences ($p \leq 0.05$) between firmness of stem (S) and blossom (B) portions of cucumbers. Breene et al. (1972) explained that toward the stem end, the skin tended to be thicker and the proportion of flesh was greater relative to seed cavity tissue. The results obtained in this study support this explanation.

A number of significant interactions were found, mostly involving degrees of salometer. Treatment X salometer and piece location X salometer interactions were significant; that is, the effect of degree of salometer on piece crushing force values depends on the piece location and the holding period and temperature (storage condition) of green-stock cucumbers before brining.

Slice punching and piece crushing force values are plotted in Figures 16 and 17.

Linear regression and correlation coefficients were computed between slice punching and side crushing values of salt-stock cucumbers. Mean values were used in correlations and a highly significant ($r = 0.87$) positive correlation was found between them (Figure 18).

Comparisons were made between green-stock and salt-stock punching and crushing values. High correlation ($r = 0.86$) was found between piece crushing force values of green-stock and salt-stock cucumbers (Figure 19). This suggests that measurement of side crushing in green

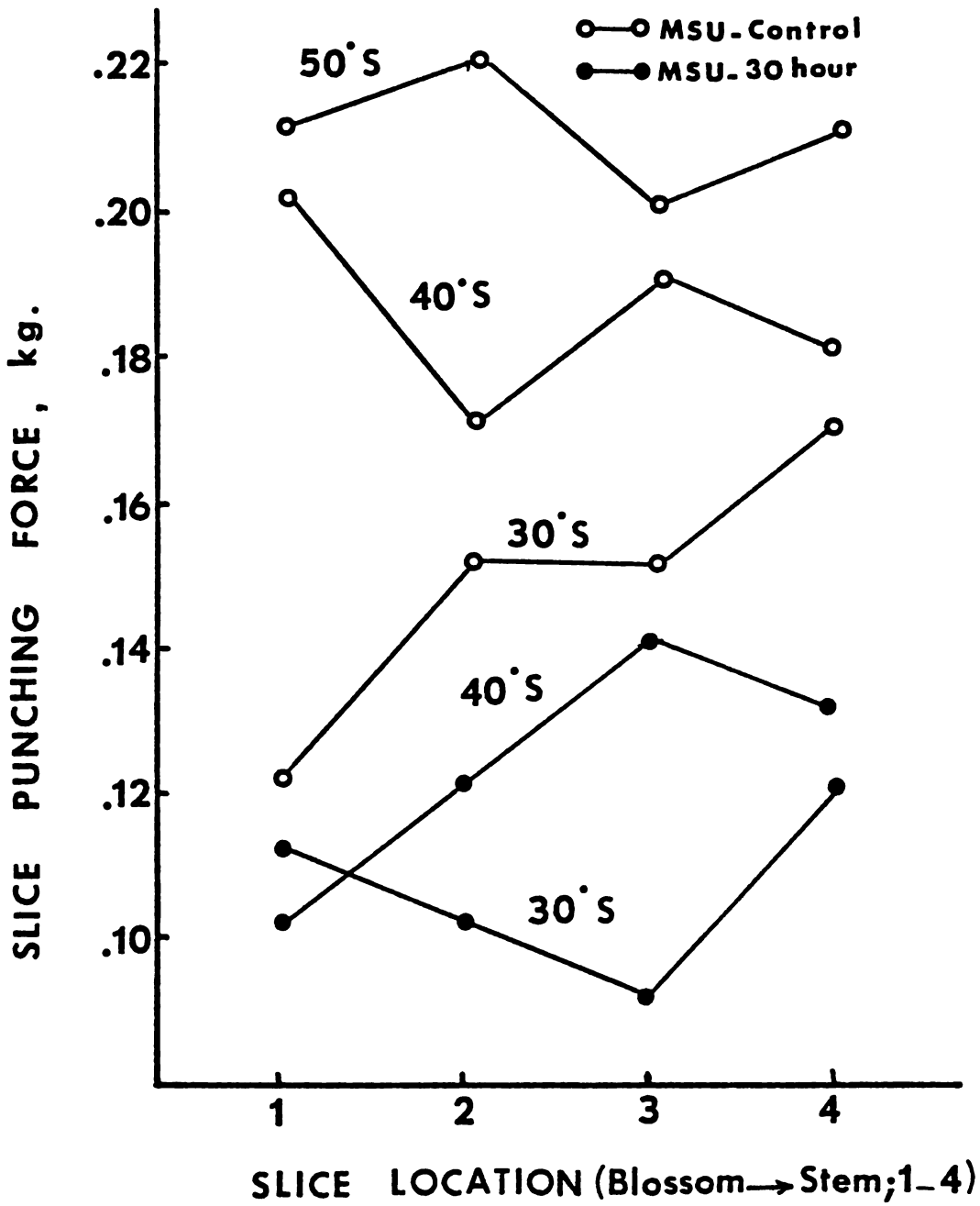

Figure 16. Slice punching force values vs. slice location of salt-stock cucumbers at various salt concentrations. (No data available for 50°S MSU-30 hour salt-stock cucumbers.)

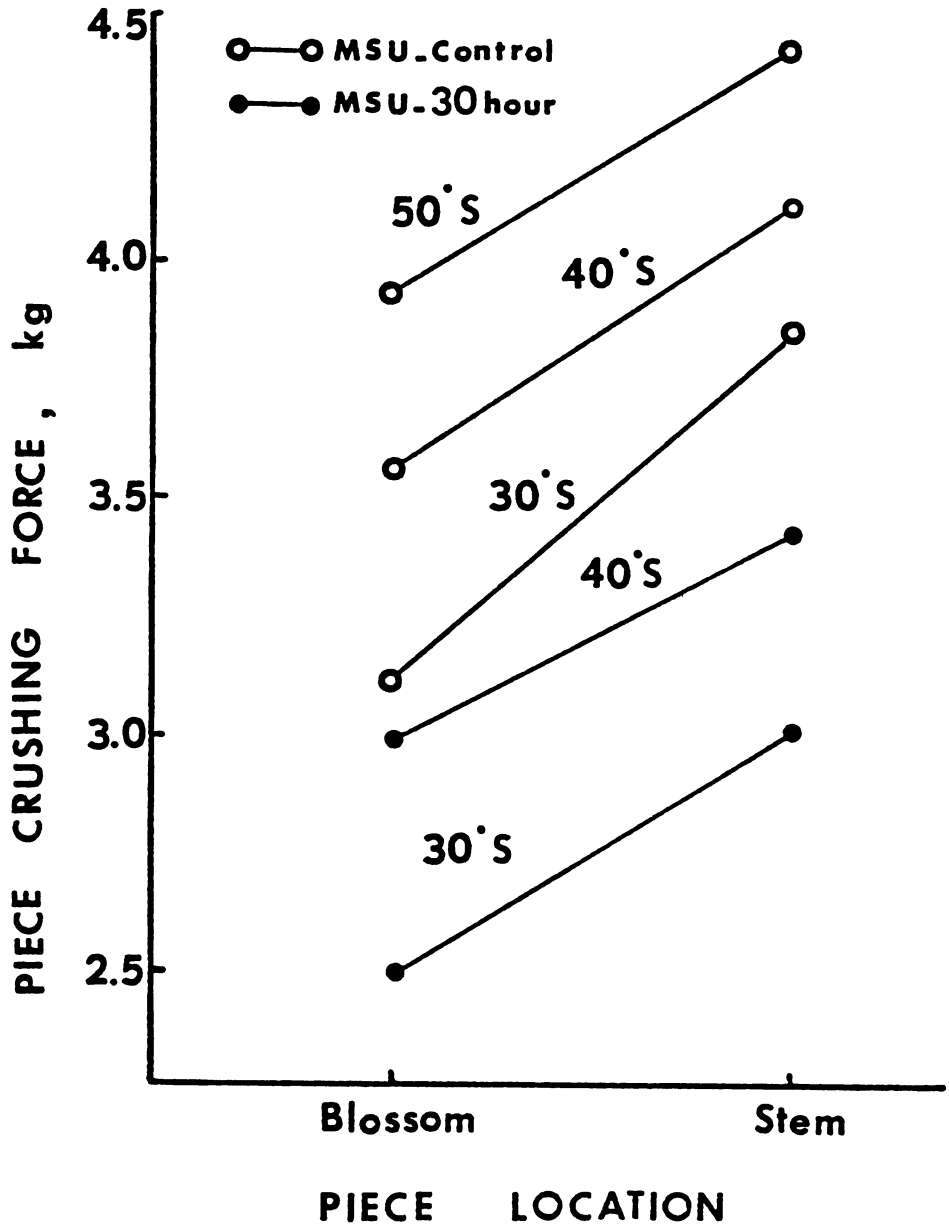

Figure 17. Side crushing force values vs. piece location of salt stock cucumbers at various salt concentrations.

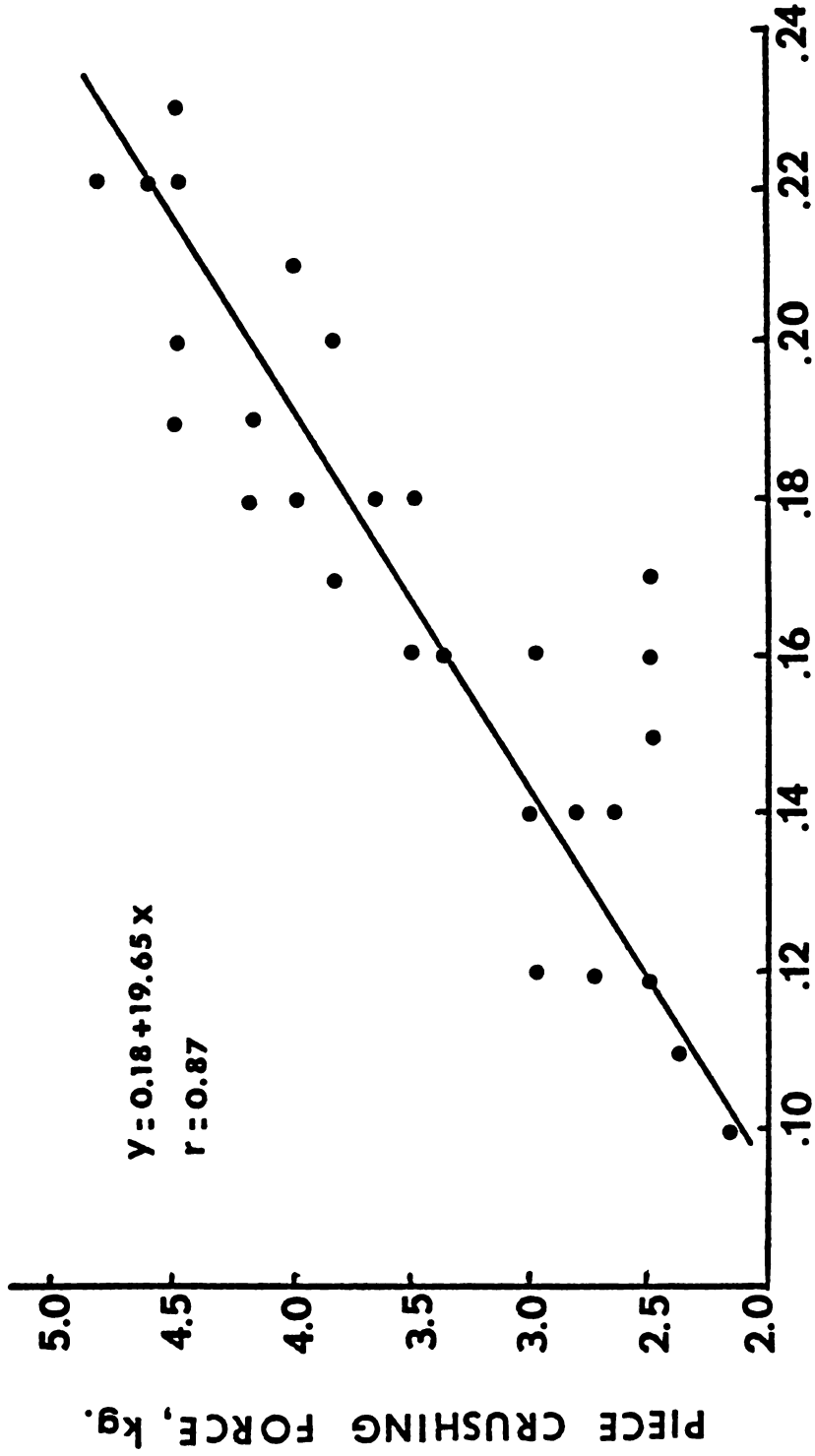

Figure 18. Regression equation and correlation coefficient for slice punching values of salt-stock cucumbers vs. piece crushing force values of salt-stock (n=50 cucumbers).

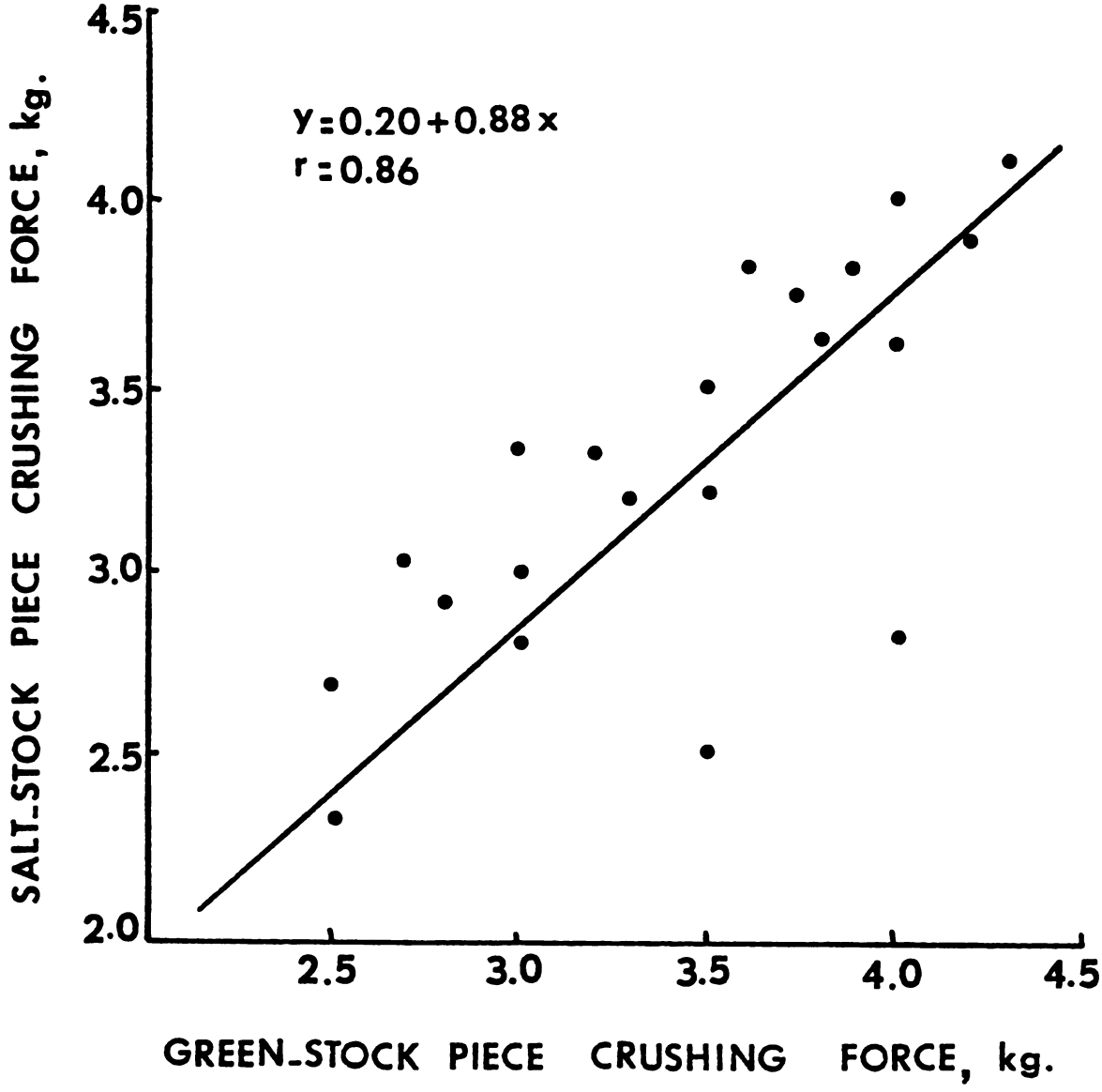

Figure 19. Scatter diagram, regression equation and correlation coefficient for piece crushing values of salt-stock cucumbers vs. piece crushing values of green-stock (80 mean values of 40°S salt-stock cucumbers were used.)

cucumbers is one means of predicting brining quality of a given green-stock. Regression equations and correlation coefficients are presented in each figure.

A good correlation ($r = 0.73$) was shown between slice punching of green and salt-stock cucumbers (Figure 20) even though the range of variation in slice punching between and within the treatments was quite narrow. These findings are in agreement with Breene et al. (1973) who showed that firmness measurement on green fruit gives a good indication of firmness that can be expected in salt-stock.

Magness-Taylor Fruit Pressure Tester (FPT). The Magness-Taylor pressure values of salt-stock cucumbers are shown in Figures 21 and 22. The highest values were obtained from the MSU-control salt-stock. Commercial Harvest I and Harvest II values were higher than MSU-30 hour late brined cucumbers. Salt concentrations did not affect the FPT values.

Calcium and Magnesium. Lampi et al. (1958) reported that there was no correlation between calcium contents of the salt-stock cucumber tissues and firmness. They also found that calcium seemed to be higher in the softer salt-stock. In contrast, it was found in our study that firm salt-stock contained higher calcium (225 ppm) than did the soft stock (180 ppm). Therefore, a good correlation between firmness as measured by the fruit pressure tester and calcium content of the tissue could be made. Magnesium content of firm and soft salt-stock cucumbers, however, was nearly constant (Table 8).

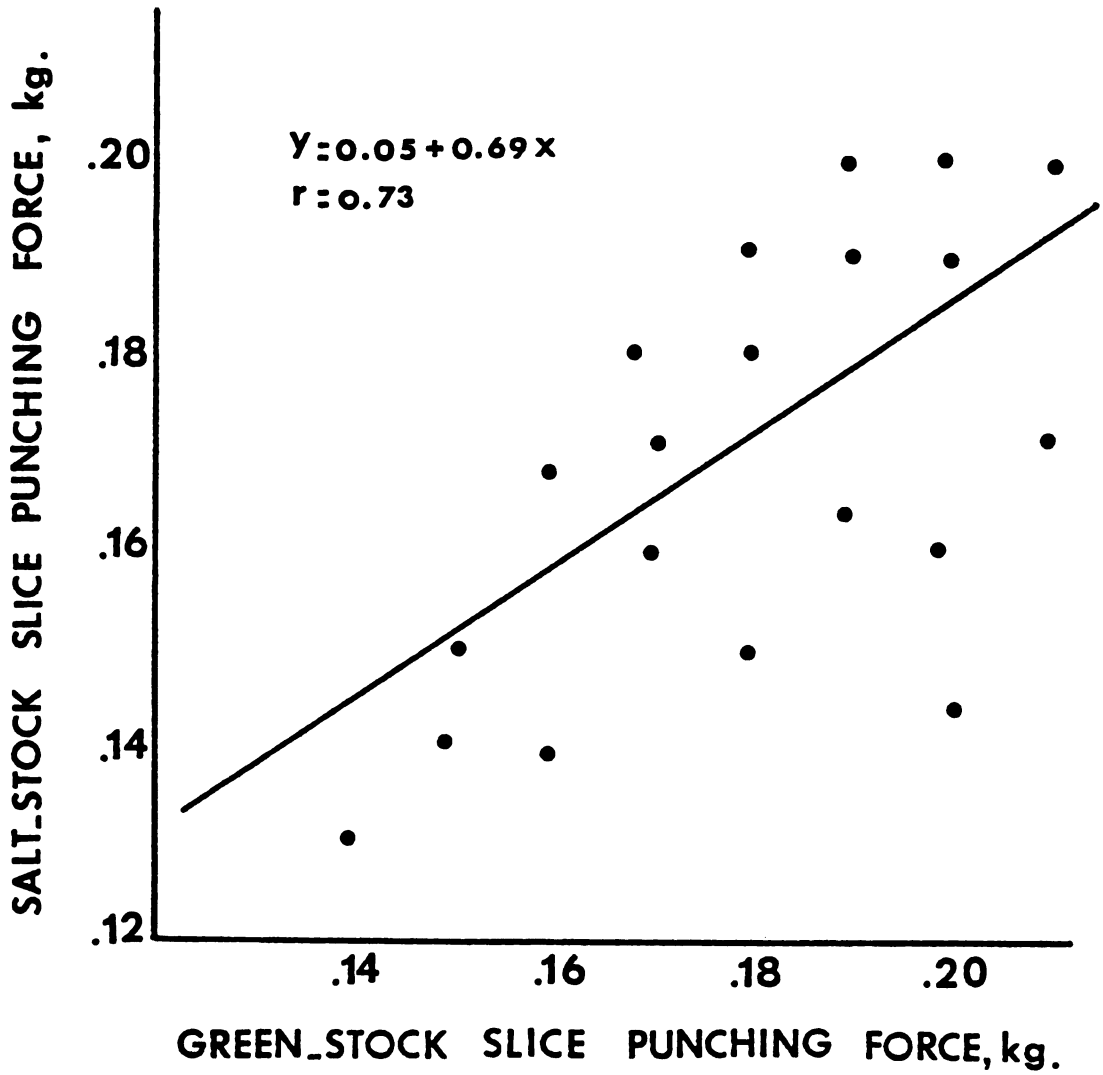

Figure 20. Scatter diagram, regression equation and correlation coefficient for slice punching force values of salt-stock cucumbers vs. slice punching force values of green-stock. (80 mean values of 40°S salt-stock cucumbers were used.)

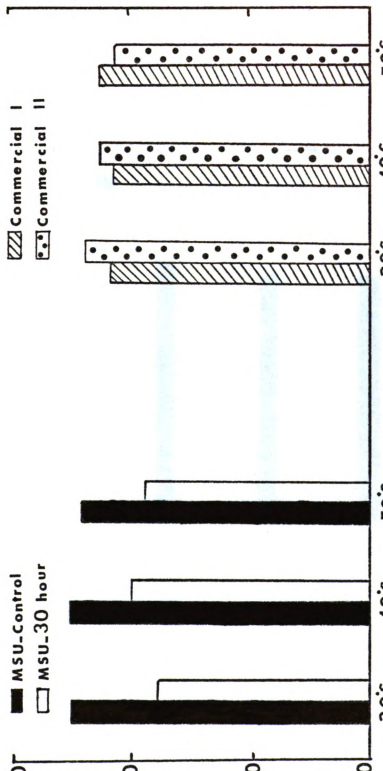

Figure 21. Magness-Taylor measurements of MSU and commercial salt-stock cucumbers at three different salt concentrations (30°, 40° and 50°S).

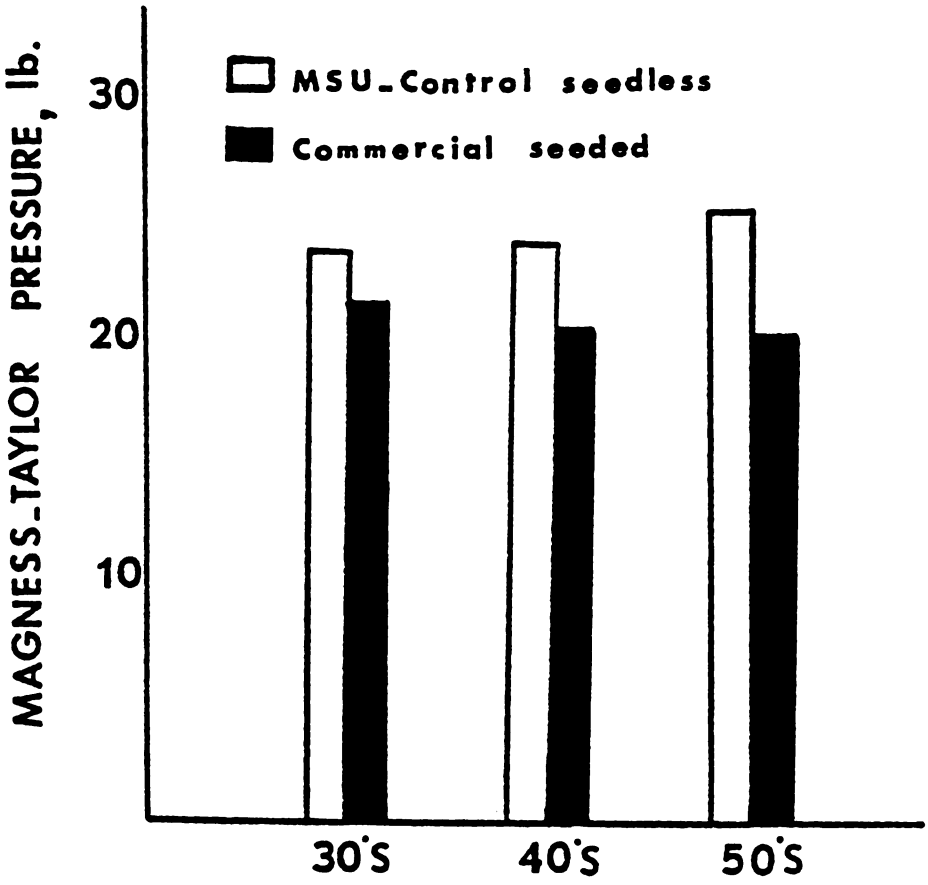

Figure 22. The comparison of firmness of MSU-seedless and commercial-seeded salt-stock cucumbers as measured by Magness-Taylor FPT.

Table 8. Comparison of the amount of calcium and magnesium and bloater defect and firmness of salt-stock cucumbers.

Salt-Stock Cucumber	Magness Taylor lb.	Ca ppm	Mg ppm	Undamaged Stock %	Bloater Defect %			
					Balloon	Lens	Honeycomb	Soft Center
Firm	22.3	225	150	68	10	--	20	2
Soft	20.4	180	148	1	27	5	52	15

1-Gallon Jar Pilot Brining Study

Pectinolytic Activity

Pectinolytic activity in each jar was determined during the fermentation by means of viscosity measurements. At the end of the fermentation period, salt-stock cucumbers were evaluated visually for bloater-type defects and enzymatic softening. The Magness-Taylor FPT was used for determination of firmness.

The enzymatic study results are summarized in Tables 9 and 10. No damage was observed in control cucumbers and pectinolytic activity was found to be very low. The cucumbers treated with firm-inside and soft-inside homogenated salt-stock cucumbers gave higher pectinolytic activities than did the cucumbers mixed with outside parts of salt-stock cucumbers. In addition to their high pectinolytic activity, percent bloater-type defects and soft center counts were also found to be high. Moderate and advanced enzymatic softening had occurred in these jars. Some cucumbers were extremely mushy and disintegrated. As reported by Bell et al. (1951), pectinolytic enzymes were more highly active in the seed part of the cucumber fruit than in the skin and flesh parts. The deesterifying pectic enzyme pectinase splits the pectic and cellulosic substances which make up the primary structural element in the cell wall of the cucumber. The ANOVA analysis (Table 11) shows that highly significant ($p \leq 0.1$) increases in pectinolytic activity units occurred as soft-inside and firm-inside salt-stock cucumbers were used (Figure 23).

The cucumbers treated with soft salt-stock brine and soft salt-stock pickle showed 45 and 40 pectinolytic activity units, respectively, which are considered to be very strong enzyme activity ratings.

Table 9. Effects of soft and firm salt-stock cucumbers and sorbate treatment on enzyme activity, percent bloater defect, softening and firmness of control cucumbers.

Treatment	Undamaged Stock %	Bloater Defect %			Soft Center Count of 10	Pectinolytic Activity % Viscosity lost	Pectinolytic Activity Units	Magness-Taylor[1] Firmness lb
		Honeycomb	Lens	Balloon				
Control (C)	100	0	0	0	0	8	9	22.0
C + Soft stock(SS)								
C + SS brine	30	40	10	20	1	40	45	18.0
C + SS pickle	50	20	10	20	2	34	40	18.4
C + Firm pickle(FP)								
C + FP inside	10	20	30	40	4	30	44	18.5
C + FP outside	80	20	0	0	0	8	17	19.7
C + Soft pickle(SP)								
C + SP inside	0	60	0	40	5	40	48	18.1
C + SP outside	80	20	0	0	1	28	30	18.7
0.1% Sorbate (S)								
C + S	80	10	0	10	0	6	7	21.7
C + SS brine + S	90	10	0	0	0	8	9	21.0
C + SS pickle + S	80	20	0	0	0	8	9	20.3

[1]Mean values, n=10 measurements.

Table 10. Effect of different salt concentrations (25° thru 50° S) on pectinolytic enzyme activity and on quality of cucumbers.[1]

Degrees of Salometer °S	Undamaged Stock %	Bloater Defect %			Soft Center Count of 10	Pectinolytic Activity %		Magness-Taylor Firmness[1] lb
		Honeycomb	Lens	Balloon		Viscosity loss	Units	
25	70	20	10	-	2	18	23	18.0
30	80	20	--	-	1	20	19	19.1
35	40	60	--	-	1	18	20	19.5
40	20	70	--	10	-	13	16	19.4
45	--	10	--	90	-	10	9	21.7
50	20	40	--	40	-	8	6	22.6

[1]Mean values, n=10 measurements.

Table 11. Analysis of variance of pectinolytic activity units in brine of 1-gallon jar cucumbers treated under various brining conditions.

Source of Variation	Degrees of Freedom	Mean Squares
1. C + SS		
Treatment	2	3714***
Days	4	45***
T x D	8	8***
Error	15	9
2. C + FP		
Treatment	2	3120***
Days	4	13***
T x D	8	4**
Error	15	12
3. C + SP		
Treatment	2	3356***
Days	4	9***
T x D	8	18***
Error	15	5
4. C + 0.1% S		
Treatment	3	2.6
Days	4	5.8**
T x D	12	1.4
Error	20	4.2
5. C + salometers		
Treatments	5	426***
Days	4	10***
T x D	20	7***
Error	30	4.9

C=control; SS=soft stock; FP=firm pickle; SP=soft pickle; S=sorbate

**Significant at $p \leq 0.01$.

***Significant at $p \leq 0.001$.

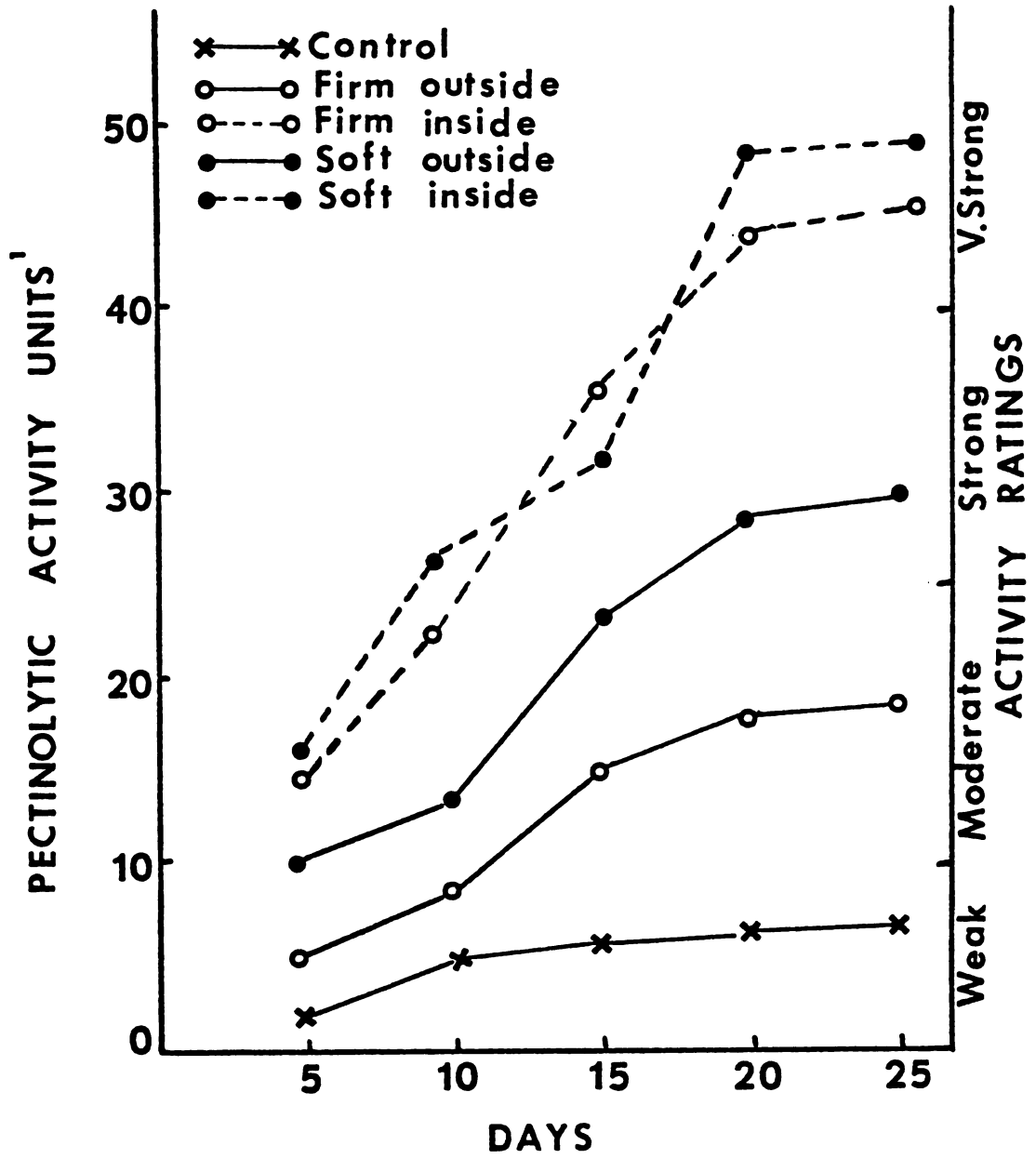

Figure 23. Pectinolytic activity in brine of cucumbers treated with firm and soft salt-stock cucumbers.

[1]According to Bell et al. 1955; 100 units = 50% viscosity loss.

These results showed that soft salt-stock had high initial brine and pickle enzyme activity which affected the control stock (Figure 24).

Addition of 0.1% sorbate reduced the percent defect and enzymatic softening by preventing the pectinolytic activity. On the other hand, these cucumbers can only be categorized fair because of their greenish-blue color which is not desired for salt-stock purpose. The similar result in color change with sorbic acid has been reported by Costilow et al. (1955).

The effect of different salt concentrations on pectinolytic enzyme activity decreased and the firmness of the salt-stock increased. Analysis of variance (Table 11) also indicates the high significant ($p \leq 0.1$) between the enzyme activity and salt concentration. The firmness of the salt-stock was found to be in direct relationship to salt concentration and inversely related to the activity of the pectinolytic enzyme. However, percent bloater defect was found to be higher as the salt concentration increased. Figure 25 shows the pectinolytic enzyme activity units during the fermentation period. Pectinolytic activity continued to increase until the high degree of salometer was attained. After it was maintained, enzyme activity decreased.

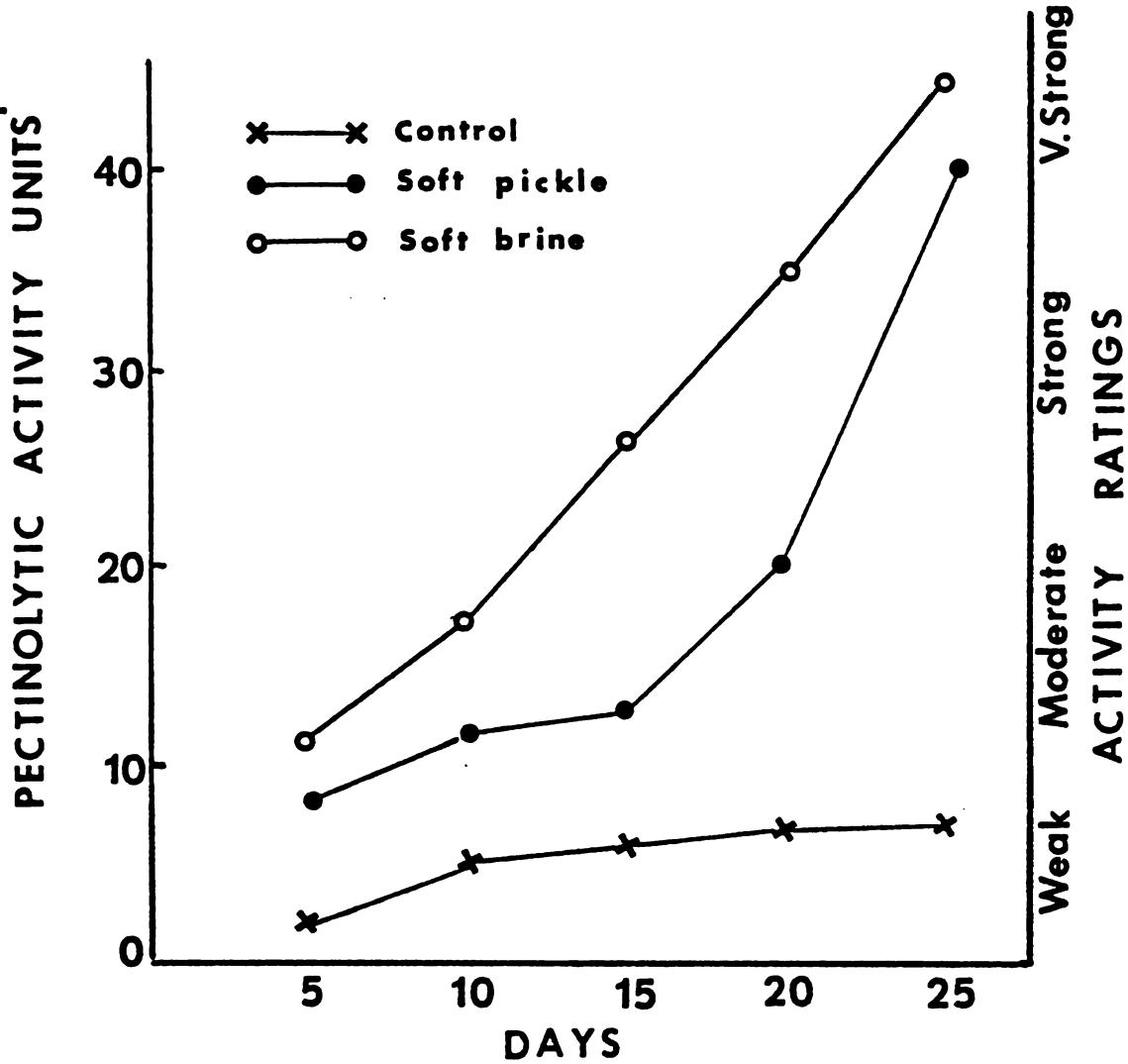

Figure 24. Pectinolytic enzyme activity in cucumber brine treated with soft stock brine and pickle.

[1]According to Bell et al., 1955; 100 units = 50% viscosity loss.

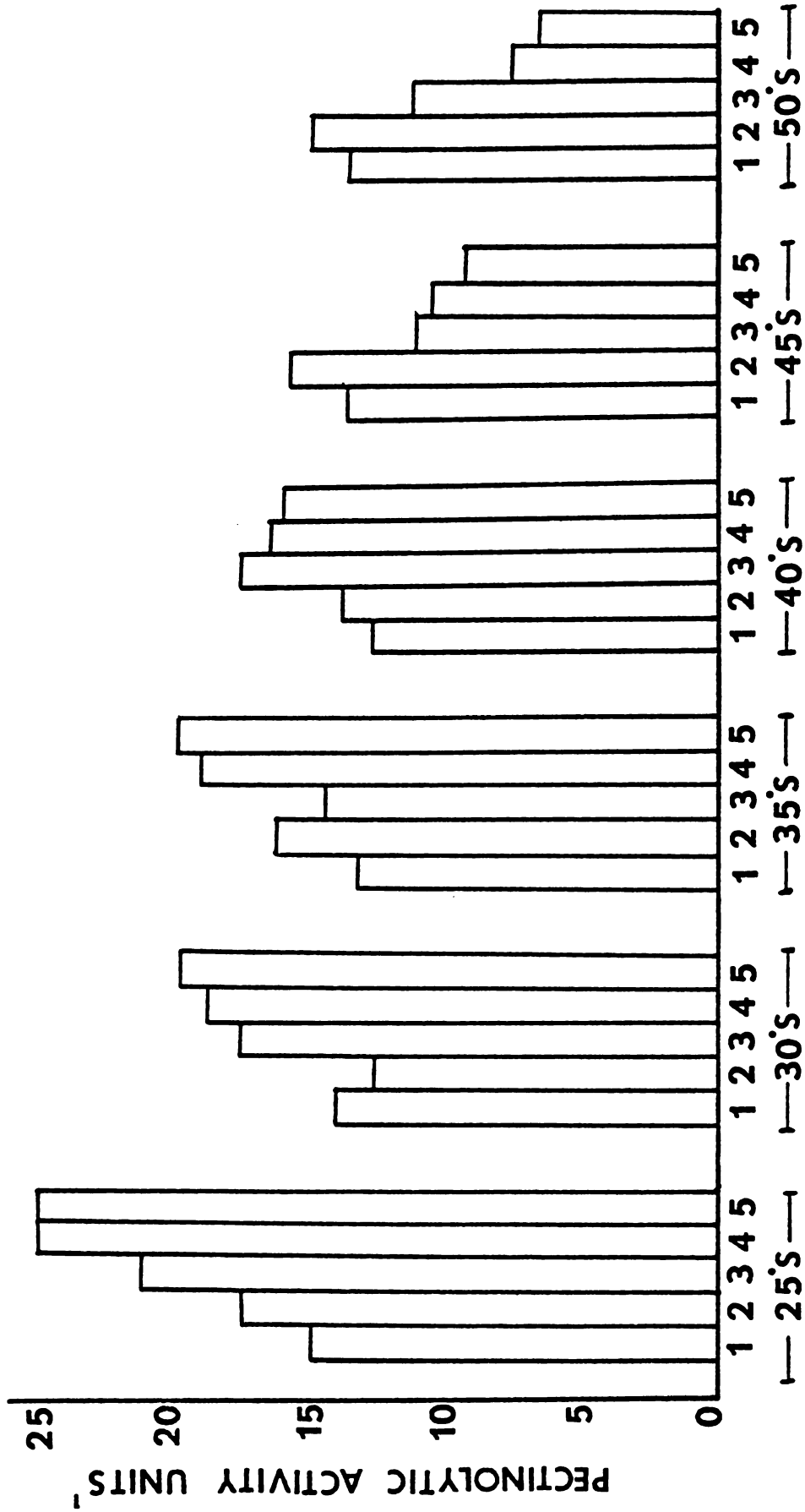

Figure 25. Pectinolytic enzyme activity of cucumbers during the fermentation of different (25^{0} through 50^{0}S) salt concentrations (enzyme activity was determined 5 times at 5 day intervals).

[1]According to Bell et al., 1955; 100 units = 50% viscosity loss.

SUMMARY AND CONCLUSIONS

The factors affecting the quality of salt-stock cucumbers were examined over a two year period. Experiments involved the fermentation of MSU-seedless vs. commercial-seeded cucumbers at three different salt concentrations (30^{o}, 40^{o} and 50^{o}S). The effect on salt-stock quality of holding the green-stock cucumbers before brining was also examined. Textural evaluation of green and salt-stock cucumbers was carried out using the Instron Universal Testing Machine and the Magness-Taylor fruit pressure tester (FPT). Visual evaluation was performed for percent bloater-type defects and soft center development.

Results indicated increased bloater-type defects and decreased firmness when cucumbers were held for 30 hours at 30^{o}C before brining. Balloon and honeycomb-type defects were common and nitrogen purging failed to control the CO_2 levels in these pails. MSU control-seedless cucumbers which were hand harvested gave the best results for salt-stock quality. They were preferred over commercial-seeded salt-stock cucumbers. The study suggested that salt-stock quality would be improved if cucumbers were brined immediately after harvesting. Salt concentration was effective in controlling bloater-type defects of commercial salt-stock cucumbers. Reduced bloater defected salt-stock was obtained as the final salt concentration was increased.

Slice punching ($r = 0.76$) and side crushing ($r = 0.86$) Instron values showed a good correlation between green-stock and salt-stock measurements. This confirms that firmness measurement on green-stock gives a good indication of firmness that can be expected in salt-stock.

Calcium and magnesium determination on firm and soft salt-stock cucumbers by atomic absorption indicated that firm salt-stock contained higher calcium (225 ppm) than soft stock (180 ppm). Magnesium content did not differ in either the firm or soft salt-stock cucumbers.

Studies of pectinolytic enzyme activities in salt-stock brine were carried out in one-gallon jars filled with cucumbers treated with various parts of soft and firm salt-stock cucumbers and brine. The effect of sorbic acid and six different concentrations (25^{o} through 50^{o}S) on pectinolytic activity was determined.

Results indicated that pectinolytic enzymes were more highly active in the interior of the salt-stock cucumbers than in the exterior portions. The high enzyme activity increased the percent bloater-type defects and soft center counts. Sorbic acid was found to be effective in inhibition of pectinase, but it adversely affected the color (greenish-blue) of salt-stock cucumbers. The firmness of the salt-stock was found to be in direct relationship of salt concentration and inversely related to the activity of the pectinolytic enzymes.

RECOMMENDATIONS FOR FURTHER RESEARCH

1. Relation of high final degrees of salometer and bloater-type defect occurrence during the fermentation of cucumbers.

2. Effect of less than 0.1% sorbate on salt-stock cucumber softening.

3. Emphasis on seedless cucumber fermentation.

LIST OF REFERENCES

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AOAC. 1970. "Official Methods of Analysis," 12th Ed. Association of Official Agricultural Chemists, Washington, D.C.

Apeland, J. 1961. Factors affecting the keeping quality of cucumber. Internatl. Inst. Refrig. Bul. Sup. 1:45.

Baker, L. R., J. W. Scott and J. E. Wilson. 1973. Seedless pickles--A new concept. MSU Agr. Exp. Station Research Report.

Bell, T. A., L. W. Aurand and J. L. Etchells. 1960. Cellulose inhibitor in grape leaves. Botan. Gaz. 122:143.

Bell, T. A. and J. L. Etchells. 1950. Softening of commercial cucumber salt-stock in relation to polygalacturonase activity. Food Tech. 4:157.

Bell, T. A. and J. L. Etchells. 1958. Softening enzyme activity of cucumber flowers from northern production areas. Food Research 23:198.

Bell, T. A. and J. L. Etchells. 1961. Influence of salt (NaCl) on pectinolytic softening of cucumbers. J. Food Sci. 26:84.

Bell, T. A., J. L. Etchells and I. D. Jones. 1951. Pectinesterase in the cucumber. Arch. Biochem. Biophys. 31:431.

Bell, T. A., J. L. Etchells and I. D. Jones. 1955. A method for testing cucumber salt stock brine for softening activity. ARS, USDA. ARS-72-5, 15.

Bell, T. A., J. L. Etchells and J. A. Singleton. 1965. Inhibition of pectinolytic and cellulolytic enzyme in cucumber fermentations by sericea. J. Food Sci. 30:233.

Bourne, M. C. 1968. Texture profile of ripening pears. J. Food Sci. 33:223.

Breene, W. M., D. W. Davis and H. E. Chou. 1972. Texture profile analysis of cucumbers. J. Food Sci. 37:113.

Breene, W. M., D. W. Davis and H. E. Chou. 1973. Effect of brining on objective texture profiles of cucumber varieties. J. Food Sci. 38:210.

Breed, R. S., E. G. D. Murray and N. R. Smith. (Editors) 1948 Bergey's Manual of Determinative Bacteriology. 6th Edition.

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

Costilow, R. N., F. M. Coughlin and E. K. Robbins. 1957. II. Effect of sorbic acid on the yeast and lactic acid fermentations in brined cucumbers. Appl. Microbiol. 5:373.

Costilow, R. N. and F. W. Fabian. 1953. Microbiological studies of cucumber fermentations. Appl. Microbiol. 1:314.

Costilow, R. N., W. E. Fergugon and S. Ray. 1955. Sorbic acid as a selective agent in cucumber fermentations. I. Effect of sorbic acid on microorganism associated with cucumber fermentations. Appl. Microbiol. 3:341.

Costilow, R. N. and M. A. Uebersax. 1978. Mimeograph Bulletin.

Etchells, J. L. and T. A. Bell. 1955. Cucumber blossoms in salt-stock mean soft pickles. Research and Farming. N. C. Agr. Expt. Sta. 13(1-4):14.

Etchells, J. L., T. A. Bell, R. J. Monroe, P. M. Masley and A. L. Demain. 1958(a). Populations and softening enzyme activity of filamentous ungi on flowers, ovaries, and fruit of pickling cucumbers. Appl. Microbiol. 6:427.

Etchells, J. L., T. A. Bell and H. P. Fleming. 1973. Suggested procedure for the controlled fermentation of commercially brined pickling cucumbers. Pickle Pac. Science. Vol. 3.

Etchells, J. L., T. A. Bell and C. F. Williams. 1958(b). Inhibition of pectinolytic and cellulolytic enzymes in cucumber fermentations by scuppernong grape leaves. Food Technol. 12:204.

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

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

Etchells, J. L. and I. D. Jones. 1951. Progress in pickle research. Glass Packer. 30:4 264.

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

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

Fellers, P. J. and I. J. Pflug. 1967. Storage of pickling cucumbers. Food Technol. 21:74.

Fleming, H. P., W. Y. Cobb, J. L. Etchells and T. A. Bell. 1968. The formation of carbonyl compounds in cucumbers. J. Food Sci. 33:572.

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

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

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

Fleming, H. P. and R. L. Thompson. 1978. Susceptibility of pickling cucumbers to bloater damage by carbonation. J. Food Sci. 43:892.

Fleming, H. P., R. L. Thompson and T. A. Bell. 1978. Controlled fermentation of sliced cucumbers. J. Food Sci. 43:888.

Fleming, H. P., R. L. Thompson, J. L. Etchells, R. E. Kelling and T. A. Bell. 1973(b). CO_2 production in the fermentation of brined cucumbers. J. Food Sci. 38:504.

Friedman, H. H., J. E. Whitney and A. S. Szczesniak. 1963. The texturometer--a new instrument for objective texture measurement. J. Food Sci. 28:390.

Garte, L. and J. Weichmann. 1974. Symposium on vegetable storage. 38(II):373.

Jacobs, M. B. 1958. The chemical analysis of foods and food products. Third edition. Van Nostrand Co. Canada.

Jeon, I. and W. M. Breene. 1973. Texture of cucumbers: correlation of instrumental and sensory measurements. J. Food Sci. 38:334.

Joffe, F. M. 1959. Heat induced softening in fresh cucumber pickles. M.S. thesis. M.S.U. Library.

Jones, I. D. and J. L. Etchells. 1943. Physical and chemical changes in cucumber fermentation. Food Inds. 15:62.

Jones, I. D. and J. L. Etchells. 1950. Cucumber varieties in pickle manufacture. Canner. 110(1):34.

Jones, I. D., J. L. Etchells and R. J. Monroe. 1954. Varietal differences in cucumbers for pickling. Food Technol. 8:415.

Jones, I. D., J. L. Etchells, O. Veerhoff and M. K. Veldhuis. 1941. Observations on bloater formation in cucumber fermentation. Fruit Prods. J. 20:202.

Lampi, R. A., W. B. Esselen and C. L. Thompson. 1958. Changes in pectic substances during fermentation and softening. Appl. Microbiol.

Lingle, M. 1975. Controlled fermentation of cucumbers--The how's and why's--. Food Production/Management. July.

Magness, J. R. and G. F. Taylor. 1925. An improved type of pressure tester for the determination of fruit maturity. USDA Dept. Circ. No. 350.

Marshall, D. E. and J. H. Levin. 1975-76. Pickle research. Michigan State Univ. Agr. Expt. Sta. Tech. Bull. East Lansing.

Marshall, D. E., B. F. Cargill an Jordan. 1972. Physical and quality factors of pickling cucumbers as affected by mechanical harvesting. Transactions of the ASAE. 15:604.

McCombs, C. L., H. N. Sox and R. L. Lower. 1976. Sugars and dry matter content of cucumber fruits. Hort. Science. 11:245.

McCreight, J. D., R. L. Lower and D. M. Pharr. 1978. Measurement and variation of sugar concentration of pickling cucumber. J. Amer. Coc. Hort. Sci. 103(2):145.

Morris, L. L. and L. K. Mann. 1946. Effect of volatile from honey due melons on the storage behavior of certain vegetables. Amer. Soc. Hort. Sci. Proc. 47:368.

Nicholas, R. C. 1960. Some observations on the use of fruit pressure testers. Mich. Agr. Expt. Sta. Quart. Bull. 43:312.

Pederson, C. S. and M. N. Albury. 1950. The effect of temp. upon bacteriological and chemical changes in fermenting cucumbers. New York State Agr. Expt. Sta. Bull. T44.

Pederson, C. S. and M. N. Albury. 1962. The absorption of salt by cucumbers during fermentation. Food Technol. 16(5):126.

Pflug, I. J., F. M. Joffe and R. C. Nicholas. 1960. A mechanical recording pressure tester. Mich. Agr. Expt. Sta. Quart. Bull. 43:117.

Pharr, D. M., H. N. Sox, E. L. Smart, R. L. Lower and H. P. Fleming. 1977. Identification and distribution of soluble saccharides in pickling cucumber plants and their fate in fermentation. J. Amer. Soc. Hort. Sci. 102(4):406.

Phillips, G. F. and J. O. Mundt. 1950. Sorbic acid as an inhibitor of scum yeast in cucumber fermentations. Food Technol. 4:291.

Quinn, E. L. and C. L. Jones. 1936. "Carbon Dioxide." Reinhold Pub. Corp., New York.

Raymond, F. L., J. L. Etchells, T. A. Bell and P. M. Masley. 1959. Filamentus fungi from blossoms, ovaries, and fruit of pickling cucumbers. Mycologia. 51:492.

Ryall, A. L. and W. J. Lipton. 1978. Second edition. Handling, transportation and storage of fruits and vegetables. AVI Vol. 1.

Shoup, J. L. 1975. Salt free acidulant storage of pickling cucumbers. J. Food Sci. 40:689.

Sokal, R. R. and F. J. Rohlf. 1969. Biometry. Freeman Co. San Francisco.

Szczesniak, A. S., M. A. Brandt and H. H. Friedman. 1963. Development of standard rating scales for mechanical parameters of texture and correlation between the objective and the sensory methods of texture evaluation. J. Food Sci. 28:397.

Szczesniak, A. S. and M. C. Bourne. 1969. Sensory evaluation of food firmness. J. Texture Studies. 1:52.

Weier, T. E. and C. R. Stocking. 1949. Histological changes induced in fruits and vegetables by processing. Adv. in Food Research. 2:297.