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EFFECT OF POSTHARVEST HOLDING CONDITIONS
ON THE QUALITY OF CUCUMBER PRODUCTS

By

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ABSTRACT

EFFECT OF POSTHARVEST HOLDING CONDITIONS ON THE QUALITY OF CUCUMBER PRODUCTS

By

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Evaluation of the effect of postharvest holding conditions on cucumber product quality was conducted in four studies.

Increasing temperatures and times prior to brining resulted in soft texture, high respiration rate, increased weight loss, and a decrease in salt-stock quality. Cucumbers held at 5°C for up to six days retained high quality.

Holding cucumbers at refrigerated temperatures for two and three days or for one day followed by 28°C exposure for an additional day did not adversely affect quality.

Relative humidity had limited effect on composition and texture of cucumbers held two days at 2 and 28°C; however, cucumber moisture loss was significant under 0% and 75% RH.

Green-stock texture was generally firmer at the stem end than at the blossom end. Significant correlations were shown between salt-stock textural evaluations by the FPT and Instron puncture tests. Poor correlations were detected between instrumental and sensory measures of fresh-pack pickle spears.

To my parents

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INTRODUCTION

The acreage of cucumbers grown for pickle manufacture is one of the largest of the national truck crops grown for processing. Michigan is the leading state in pickling cucumber production with over 100,000 tons annually valued at over ten million dollars.

At present approximately half of the total crop is utilized in the manufacture of fresh or uncured stock which is packed from the fresh state and is pasteurized in suitable spiced brines or light syrup for preservation. The remaining crop is brined at time of harvest, cured by fermentation, and stored until needed for further processing and manufacture into finished pickle products.

Cucumber pickles are not known for nutritional characteristics, but rather are consumed for their desirable crisp texture and fine flavor. Due to the rapid increased consumption of pickles throughout the world, considerable research effort has been devoted to compositional, genetic, handling, and processing factors affecting pickle quality.

The trend to harvest larger cucumbers, brought on by increased mechanization, has resulted in increased bloater damage and softening of cucumbers during bring preservation.

Bloater damage is caused by a buildup of carbon dioxide in the brine, which results in gas pockets inside the cucumbers. Carbon dioxide in the brine originates from the cucumber tissue and from microbial activity in the brine. Cucumber softening is considered to be the result of action by pectic enzymes on the pectin composing the middle lamella of cucumber tissue during the active fermentation period.

The purging process during natural and controlled fermentation is highly effective in preventing bloater type damage; however, the problem of softening in large cucumbers is not eliminated by this process.

The unfavorable postharvest holding environments and the extended transit times from growing areas to the manufacturing plants often result in undesirable salt-stock quality as well as decreased fresh-pack pickle quality.

The present work was undertaken in an attempt to evaluate the effects of postharvest holding conditions on the quality of cucumber products. Four independent studies were conducted. The first study was designed to evaluate the quality change of green- and salt-stock cucumbers held at different temperatures for up to six days prior to brining. The second study was to determine the effects of cucumber size and holding temperature and time on the quality of green-stock, salt-stock, and fresh-pack pickles. The third study was designed to evaluate the effect of refrigerated temperatures followed by subsequent exposure to a higher temperature on the quality of cucumber products.

The fourth study involved the determination of the effects of cucumber variety, holding temperature, and humidity on the quality of green-stock and fresh-pack pickles.

REVIEW OF LITERATURE

Postharvest Holding of Green-Stock Cucumbers

Effect of Mechanical Harvesting and Handling

Cucumbers for the fresh market are almost entirely hand harvested. However, pickling cucumbers are widely harvested by machine using a once-over vine-destructive system. Mechanically harvested cucumbers have more damaged cucumbers than those which are hand harvested. Up to 50% of cucumber fruits were damaged by the mechanical harvesting system. This damage included broken and smashed fruit as well as cuts, abrasions, ground-in soil and bruises on the fruit (Marshall *et al.*, 1972b). Cargill *et al.* (1974) indicated that proper harvester adjustments will result in increased field recovery and fewer damaged cucumbers.

Handling of green-stock cucumbers between mechanical harvesting and further processing usually results in various types of quality reductions. Eaks and Morris (1956b) reported that mechanical injury during harvesting and handling provided an avenue for water loss and infection by decay organisms. Research by Marshall *et al.* (1971a,b 1972a) provided the first indication that handling increased

internal defects and bloating in brine stock pickles. They found that mechanical harvesting did not cause increased frequency of bloating, but that the various subsequent steps of handling caused bloating to increase 3 to 5 times. A similar study by Sarig et al. (1975) again confirmed a definite trend toward increased bloater formation with increases in handling steps.

Marshall et al. (1972b) reported that impact and pressure due to harvesting and handling can cause unseen physical damage which can lead to increased carpel separation and increased bloating in salt-stock cucumbers. Heldman et al. (1976) identified various steps during handling which contribute most to quality defects. They concluded that the visible damage to the green-stock cucumbers was promoted by handling steps different from those which promoted bloater formation. The extent of visible damage of green-stock cucumbers was closely related to drop distance and to the number of cucumbers involved in any transfer operation. Large magnitude drops (drop heights greater than 2.5 ft.) caused most damage. The frequency of bloating, however, appeared to be most closely associated with handling steps (especially size-grading) which caused damage due to high frequency of low-magnitude drops.

The drop studies conducted by Marshall et al. (1972b) showed that use of foam rubber (3 in. minimum) instead of wood or metal on the floor of transport vehicles drastically

reduced from 40% to less than 5% the number of broken, smashed, and split cucumbers in the first few bushels.

Sarig et al. (1975) concluded that in order to minimize damage every effort should be made to reduce the number of product transfers and drop heights. Decelerating devices and cushioning materials should be used when possible.

Postharvest Physiological Changes

Compositional Changes. Development of the controlled fermentation process (Etchells et al., 1973b) for the pickling cucumber industry has brought about interest in the composition of cucumbers since certain components of the fruit serve as substrate for the fermentation organisms involved.

In the study of the relationship between fruit sizes and nutrient content of greenhouse cucumbers (cv. Burpee hybrid), Ward and Miller (1970) reported that a constant dry matter of about 4-5% was maintained once the fruits reached a size of about 30g. Davies and Kempton (1976) studied the changes in the composition of the harvested glasshouse cucumbers (Cucumis sativas cv. Brilliant) during development after flowering. In contrast to the data reported by Ward and Miller, they found that the percentage dry matter and alcohol-insoluble solids declined rapidly during the first 10 days of growth (when expressed in terms of fresh weight) and then more slowly with increasing fruit age. These two parameters were negatively correlated with log of fresh fruit weight. On the other hand, the percentage alcohol-soluble solids changed little during the first 6 days and then decreased progressively. The free sugars were found to be almost exclusively glucose and fructose, present in approximately equal amounts. Both increased rapidly for the first 6 days after flowering and then changed little until the onset of senescence. Only traces of sucrose and myoinositol were present during development.

The reducing and total sugar concentration and dry matter content of freshly harvested fruits and fruits held at 16°C for 3 days were reported by McCombs et al. (1976). The changes in fruit composition after storage were small and inconsistent for reducing and total sugar concentration and dry matter content. Large fruits (3.8 - 5.1 cm diameter) generally contained more sugars than small fruits (<2.7 cm diameter) on a fresh weight basis. Fructose, glucose and sucrose were shown to be present. Practically all the sugar detected was reducing sugar and was found at higher concentration in locule tissue than in carpel wall tissue. Correlations between reducing sugars and the refractive index varied with harvest date and cultivar, but generally were not very high. Refractive index did not appear to be an accurate indicator of sugar content.

Mack and Janer (1942) found that relatively lower percentages of dry matter were maintained in waxed fruits than in unwaxed fruits under storage conditions. The sugar content, however, showed no consistent relationship to wax treatment.

McCreight *et al*. (1978b) reported that reliable measurements of reducing sugar and total carbohydrate concentrations could be obtained from aqueous extracts of thawed, transverse slices of cucumbers. They found that reducing sugar concentration did not change after 180-day frozen storage. Reducing sugar and total carbohydrate concentrations were highly correlated with each other, and were not highly correlated with fresh fruit weight or fruit size. Cucumber fruit reducing sugar concentration averaged 31.1 and 22.6 mg/g at 2 harvest dates and ranged from 7.1 to 52.8 mg/g in a population of 585 plant introductions and cultivars.

Ideally, fermentable sugars should be utilized by lactic acid bacteria, with the exclusion of undesirable microorganisms that cause secondary fermentation and produce large quantities of CO_2. Genetic selection for lower cucumber fruit sugar concentration is, therefore, a potential tool for reducing bloater occurrence. McCreight *et al*. (1978a) reported that proper selection of a breeding scheme may be used to reduce the sugar concentration in fruit.

Cucumber fruits infected with *Pythium aphanidermatum* may cause severe economic loss in shipments. McCombs and Winstead (1964) reported that the sugar present in fruits - cellobiose, sucrose, glucose, and fructose - were rapidly

utilized by _P_. _aphanidermatum_ during the first four days of infection.

Hirose (1976b) found that malic and citric acid contents were higher in younger fruits and that in storage, malic acid content decreased as storage temperature decreased from 20 to 5°C. Davies and Kempton (1976) observed that while titratable acidity of fruit after flowering did not change significantly during development, total acidity (5-6 times higher) declined at the first few days and then steadily increased until the early stages of senescence.

In discussing the nutrient content in cucumbers, Ward and Miller (1970) found that levels of N, P, K, Mg, and Ca fell rapidly to constant levels as fruits increased in size. In contrast, Davies and Kempton (1976) reported that total and alcohol-soluble N and P increased slowly during the early stages of growth but more rapidly with increasing maturity; however, K levels tended to decrease.

The flavor of fresh cucumbers has been attributed greatly to aldehydes. Fross _et al_. (1962) have identified trans-2, cis-6-nonadienal as the major pleasant element. Fleming _et al_. (1968) have shown that the flavor was generated enzymatically when the fruit was cut or mechanically ruptured in the presence of oxygen.

The chemical structure of the aldehydes suggested that unsaturated fatty acids could be the precursors. The formation of aldehydes from the oxidation of linoleic and linolenic acids was studied by Grosch and Schwarz (1971).

They proposed that in cucumber the double bonds of the unsaturated fatty acids were broken in a dioxygenase-like reaction. Such a reaction would lead to the formation of hexanal and cis-3-nonenal from linoleic acid while proponal, cis-3-hexenal and cis-3, cis-6-nonadienal would be formed from linolenic acid. Isomerization from cis-3 to trans-2 may occur after the enzyme catalyzed oxidation to give trans-2, cis-6-nonadienal which is responsible for cucumber flavor.

The mechanism of this novel cleavage reaction of fatty acids was studied by Galliard and Matthew (1976) and Galliard and Phillips (1976). They pointed out that extracts of cucumber fruits catalyze fatty acid breakdown by two different routes. An α-oxidation system produces the long chain aldehydes that are also found in the volatile compounds formed on maceration of cucumber fruits. A lipoxygenase-mediated process causes the cleavage of polyunsaturated fatty acids to carbonyl fragments. Galliard _et al_. (1976) further indicated that hydroperoxide isomers and a hydroperoxide cleavage enzyme system were involved in the conversion of linoleic acid to its aldehydes.

Bitterness caused by the presence of triterpenoid derivatives is concentrated near the stem end of the cucumber as contended by Chandler (1965). Bitterness declines with maturity of fruits and length of storage time. Bitterness can be entirely eliminated by mild heating for a short time.

Respiration of Cucumbers. By the use of different varieties and harvesters, Garte and Weichmann (1974) concluded that pickling cucumbers harvested mechanically showed a respiration rate distinctly higher than that shown by cucumbers harvested by hand during a 5-day holding period.

Temperatures in the range from 0 to 10°C are referred to as chilling temperatures which will cause chilling injury to certain plant materials such as cucumber fruits (Eaks and Morris, 1956a). From the study of the effect of temperature on the respiration rate, Platenius (1942) concluded that the respiration rate of cold-sensitive crops (including cucumbers) held at 0.5°C did not show deviations from the results of those held at 10 or 24°C that would suggest an abnormal rate or course of respiration associated with chilling injury. Mack and Janer (1942) obtained a threefold increase in the rate of CO_2 production of cucumbers during a three-week period in the temperature range of 2.2 to 3.3°C. Both papers were in general agreement regarding that the rate of CO_2 production of cucumbers decreased with time at temperatures of 10°C or above.

Eaks (1955) found that respiration of cucumbers is a function of the oxygen content from 1 to 16% at 15°C. However, at 5°C, O_2 concentration had no influence. Eaks and Morris (1956b) indicated that at non-chilling temperatures (13 to 30°C) the rate of CO_2 production decreased with duration of storage, whereas at chilling temperatures (0 to 10°C) the rate increased with time to a plateau (at

5-10 days) that was followed by a decline. At all temperatures within the non-chilling range, cucumbers produced essentially the same total amount of CO_2 (20 gms/kg of fruit) during their entire storage life; but at chilling temperature lesser amounts were produced.

Hirose (1976a) reported the effect of temperature on CO_2 production of cucumbers, agreeing in general with that reported by Eaks and Morris (1956b). In addition, the effect of degree of maturation on respiration rates of cucumbers under chilling and non-chilling temperatures was studied. At non-chilling temperatures (20°C), rates of respiration and decreasing rates were greater in the younger fruits than in the older fruits. At chilling temperatures (less than 10°C) a peak of respiration rate appeared earlier and a change of respiration rate was greater in the younger fruits than in the older fruits. The cumulative CO_2 production before deterioration appeared to be higher in the younger fruits than in the older fruits.

As to the respiration at different relative humidities (RH's) of 75, 85, and 95%, no effect was found at 15°C; at 5°C the rate was lowest at 75% and highest at 95% (Apeland, 1961).

<u>Physical Characteristics</u>. The most important causes of loss during holding and transport of cucumbers are yellowing, loss of weight, and injury caused by unfavorable temperature and composition of the surrounding atmosphere.

Fellers and Pflug (1967) recommended a holding temperature as low as 1.1°C at 5% O_2 and 5% CO_2 controlled atmosphere. However, general recommendations for holding and transit conditions of pickling cucumber varieties have commonly been 10±2°C at a relative humidity of 80-85% or higher (Cook *et al*., 1957 ; Lutz and Hardenburg, 1977; Ryall and Lipton, 1979).

Duvekot *et al*. (1960), noting discoloration in fruit stored above 10°C, found that in controlled atmosphere of 5% CO_2 and 5% O_2, discoloration was checked and flavor remained excellent.

Apeland (1961) reported that temperatures lower than 10°C caused only little change in the color. Temperatures between 10°C and 28°C progressively affected the speed of yellowing. At 5°C the humidity had no distinct effect on yellowing; however, at 15°C the yellowing increased as the air humidity decreased from 95% to 75%. The emanations of ripening apples and tomatoes were found to have a deleterious effect on color of cucumbers. The same type of deterioration was found as an effect of small concentrations (1 and 10 ppm) of ethylene administered in the storage atmosphere. Although the best results in inhibiting yellowing were obtained in the 5% CO_2 and 5% O_2 combination, the reduction of oxygen is likely to be most important.

Cucumbers have a moisture content of about 95% and are very susceptible to rapid weight loss accompanied by visible shriveling. Fellers and Pflug (1967) reported that

the relative cucumber volume to cucumber surface area increases with cucumber size, therefore, it is rather natural for large cucumbers to store better than small cucumbers in regard to weight loss and shriveling.

The results from experiments at 5°C and 15°C in air with 75, 85, and 95% RH were presented by Apeland (1961). He found that higher temperature had a greater effect on weight loss than did lower temperature and that the loss of weight was most pronounced in the RH of 75%.

Among other factors of influence on transpiration, ethylene was found to have an enhancing effect. Transpiration can be minimized by wrapping or packing cucumbers in polyethylene (Apeland, 1961). Mack and Janer (1942) reported that waxing can also minimize transpiration and, thus, result in a reduction of weight loss.

In the study of pickling cucumbers from the time of harvest through six days of holding at various temperatures and RH's, Etchells <u>et al</u>. (1973a) found that weight loss was most rapid in 55-60% RH (lowest used) at 27°C (highest used) and averaged 25% per day from the previous weighing, with severe shriveling. The lowest rate of cucumber weight loss was at 90-95% RH with the lowest storage temperature used, 10°C.

Chilling injury, a physiological disturbance, will result in symptoms which limit marketability of cucumbers. Symptoms of chilling injury include pitting, water soaked spots and tissue collapse followed by infection with decay

organisms. Chilling injuries associated with physiological changes, discoloration and weight loss of cucumbers were reviewed previously.

Morris and Platenius (1939) showed that low temperature injury may occur in cucumbers at all temperatures between 0.6 and 15.6°C and the severity of the injury became progressively lessened as the temperature was raised. Their data were in contrast to those reported by Apeland (1961) who found that at a temperature of 7-8°C the effect of chilling injury was visible sooner than at 2°C. The relative humidity of the storage room had a pronounced effect on the rate at which pitted areas form at any one temperature, the severity of pitting being inversely proportional to the relative humidity in the storage atmosphere. They concluded that the final stage of low temperature breakdown is a localized desiccation process near the epidermis of the fruit. Any method which reduces the rate of water loss from the fruit tends to delay or prevent the formation of pitted areas even though some injury has taken place.

Eaks and Morris (1956a) reported that after exposure to chilling temperatures, accelerated deterioration occurred when the fruit was transferred to a warmer temperature of 25°C. For a given duration of exposure, maximum injury was associated with the lowest temperature. At any one chilling temperature, injury increased as the duration of exposure was lengthened.

Mack and Janer (1942) compared chemical compositional changes of cucumbers at chilling and non-chilling temperatures and found no differences in dry matter, total sugar, or reducing sugars associated with low temperature storage.

Softening of cucumbers may occur during the holding period. Joffe (1959), working with heat induced softening in fresh pickles, detected significant softening in fruits after holding only 16 hours at 4.4°C.

Esselen and Anderson (1956) found that on a basis of pressure test measurements, the raw cucumbers did not appear to soften during holding for 13 and 16 days at 2°C and room temperature, respectively. However, observations on the internal flesh of the samples did indicate an increase in softness with prolonged storage.

Apeland (1961) studied combined effects of temperature and different ethylene concentrations on firmness of cucumbers and reported that ethylene had more effect on firmness at higher temperatures (15°C) than at lower temperatures (10°C).

In addition to holding conditions, naturally occurring enzymes also have important textural implications in cucumber fruits. Bell (1951) observed pectolytic enzyme activity of cucumbers by measuring loss of viscosity of a 3% pectin solution and reported that the enzyme was found strongly active in seeds, staminate flowers, pollinated pistillate flowers, and ripe whole fruit. Green whole fruit were weakly positive or negative. Etchells *et al*. (1973a)

showed that the pectinolytic and cellulolytic enzyme activities increased with the increase of temperature and relative humidity.

Salt-Stock Pickles

Commercial Procedures for Fermentation

Natural fermentation is a commercial procedure used as a primary storage technique for fresh cucumber prior to final processing. Pickling cucumbers are usually fermented in cylindrical, wooden tanks ranging in size from 100 to 2,000 bushels with depths ranging from 5-15 ft. and diameters ranging from 8-16 ft. After the tanks are filled, they are fitted with a loosely constructed cover made of wooden boards and keyed down securely by heavier timbers. Salt brine of a suitable concentration (usually 40-45° salometer) is added to a level of a few inches above the cover. Dry salt is then added at intervals to maintain the initial brine concentration. The function of the salt in the process is to enable the desirable salt tolerant lactic acid microorganisms to ferment and produce the acid necessary for curing the cucumbers while inhibiting the growth of undesirable spoilage microorganisms as well as the softening activity of enzymes. The cucumbers and adhering particles of soil are the major sources of the microbes which use the soluble, nutritive materials, particularly sugars, as their food and cause the natural

fermentation. Their growth produces lactic and acetic acids, alcohols, and gases (CO_2 and H_2). The curing process, requiring about three months, causes the change of cucumbers from the green, opaque, buoyant fruit to olive-to-straw colored, translucent, gas-free salt-stock (Etchells and Moore, 1971).

Natural fermentation of brined cucumbers was found to be quite complex and highly variable due mainly to the heterogeneous microbiological activities. During the fermentation, the following salt-tolerant microbial groups may be active: gas-forming and nongas-forming lactic acid bacteria (Costilow et al., 1956; Etchells et al., 1964); gas-forming bacteria of Aerobacter (Etchells et al., 1945); fermentative and oxidative yeasts (Etchells and Bell, 1950a); and gas-forming, obligate, halophilic bacteria (Etchells and Moore, 1971). Of these groups, only the nongas-forming species of lactic acid bacteria are desired. However, gaseous fermentations by yeasts, coliform bacteria, and gas-forming lactic acid bacteria produce large amounts of CO_2 and result in the formation of "bloaters" (Etchells et al., 1945; Etchells et al., 1968). In addition, oxidative yeasts growing on the surface of the brines may reduce the lactic acid levels sufficiently to allow the growth of other spoilage organisms (Jones et al., 1941b).

In order to maintain a low CO_2 concentration and to reduce bloater damage of pickles, several pickle processors have attempted with little or no success to purge natural

fermentations using the procedure recommended for controlled fermentations (Etchells *et al*., 1973b).

Efficient nitrogen-purging systems were developed by Costilow *et al*. (1977) for maintaining low CO_2 concentrations in natural salt-stock pickle fermentations. The most practical system tested was a sidearm purger in which a gas diffuser with a very small pore size was used to purge the brine while the brine was being circulated. The use of these systems dramatically reduce the incidence of severe bloaters in large diameter salt-stock pickles.

To develop a feasible, bulk fermentation process for the pickle industry that will virtually eliminate the defects and spoilage commonly associated with the uncontrolled natural fermentation process of brined cucumbers, Etchells *et al*. (1973b) suggested a controlled lactic acid fermentation procedure. This procedure includes: thorough washing of the green-stock; chlorination and acidification of the cover brine; buffering with sodium acetate; inoculation with lactic acid bacteria as the starter culture; and purging to reduce the CO_2 content in the brine. The equilibrated brine strength and temperature were carefully controlled according to Etchells and Hontz (1972).

Inoculation is usually made with a special strain of *Lactobacillus plantarum* for rapid, vigorous growth and acid production. A special culture of *Pediococcus cerevisiae*, because of its good growth at rather high salt concentrations, has, in some instances, been added with *L. plantarum*

to establish an early lactic acid fermentation, especially where the desired equilibration of the brine concentration is slow, or where over-salting has occurred. The starter culture should be added about 18-24 hours after the brining and just before the second addition of salt, but 2-3 hours after the acetate addition. The acetate additive will hold the final brine pH at about 3.4 to 3.5 to ensure all the brine sugars are fermented by the starter culture (Etchells _et al_., 1973b).

Changes During Fermentation

Microbial Population. Comparisons of microbiological changes in natural and controlled fermentations were illustrated by Etchells _et al_. (1975). One day after brining, populations of lactic acid bacteria in the brines of unwashed cucumbers (natural fermentation) were 36 times those from washed-chlorinated-acidified cucumbers (controlled fermentation) before inoculation with _L. plantarum_. The lactic acid count reached a peak of 265 x 10^6/ml two days after inoculation of the controlled fermentation and then declined. Maximum lactic count of 40.5 x 10^6/ml was reached in natural fermentation four days after brining. Yeast counts were 50-100/ml in both fermentations during the first 3 days, and were less than 100/ml thereafter until seven days when a slight growth of film yeast began on the brine surface. Coliforms in the controlled fermentation were found to be 350/ml one day after brining and just before inoculation;

none was detected one day after inoculation and thereafter. In contrast, a natural fermentation contained 15,000/ml coliforms one day after brining, declined rapidly for the next three days and none was detected thereafter.

The data from Etchells and his associates, in general, were in agreement with those reported earlier by Etchells and Jones (1943a) and Costilow and Fabian (1953) except that no significant activity of coliform bacteria was noted by Costilow and Fabian.

Salt and Sugar Concentration. Cucumbers undergo rapid physical and chemical changes when they are placed in brine. There is a vigorous withdrawal of water and nutrients as well as penetration of salt brine from and into the cucumbers; therefore, a decided shrinkage of the fruit as well as a great dilution of the brine occur. Brine strength changes indicate that the greatest dilution occurs during the first 48 hours of the curing process (Jones and Etchells, 1943).

Jones and Etchells (1943) also reported that disorganization of the cucumber tissue can be caused by the brine, leading to increased permeability of the skin and the resultant diffusion of soluble substances such as sugars and other organic materials from the tissue. The microorganisms on the cucumber surfaces then utilize the sugar and perhaps other organic substances to start an active fermentation. Consequently, the concentration of sugar in

the brine increases rapidly for the first few days and then it decreases at a rapid rate until it attains a very low level.

Data from Fleming *et al*. (1973b) showed that higher initial brine concentrations resulted in higher sugar concentrations during fermentation. Etchells *et al*. (1975) reported that controlled fermentations required shorter times (within 7-10 days) for conversion of sugars to acid than did natural fermentations. Addition of sodium acetate will buffer the brine to permit *L. plantarum* to ferment all of the brine sugars. Without the buffer, 0.4 to 0.5% sugar may remain in the brine which, as a rule, is usually used by acid- and salt-tolerant, fermentative yeasts with resultant bloater formation (Etchells *et al*., 1973b).

Brine Acidity and pH. The acidity of the brine is expressed as lactic acid which is produced mainly from the fermentation of lactic acid bacteria. The change in brine pH is reflected by corresponding changes in the acid concentration of the brine. In general, % acid (as lactic) production rises rapidly during the first 4 to 10 days of brining and then more slowly with increasing fermentation time (Etchells *et al*., 1975; Fleming *et al*., 1978a).

Some workers reported that the orderly restricted development of lactic acid bacteria, by the use of increasing salt concentrations, will be reflected in correspondingly decreasing amounts of brine acid being formed,

and at slower rates (Jones et al., 1941b; Etchells and Moore, 1971; Fleming et al., 1973b). Etchells further pointed out that the use of slower rates of increasing the equilibrated brine strength (by the addition of dry salt on the head-boards) - within the salt-tolerance range for good growth by the lactic acid bacteria - favors the development of higher final levels of brine acidity, lower brine pH's, and a more desirable use of the fermentable cucumber sugars (Etchells and Moore, 1971).

Other factors such as cucumber size (Costilow and Fabian, 1953), types of fermentation, populations of natural microflora (Etchells et al., 1975), types of brine used (Palnitkar and McFeeters, 1975), and purging treatment (Potts and Fleming, 1979) were also reported to have effects on acid production in cucumber fermentations.

CO_2 Production and Bloater Formation. Bloater damage in commercially brined cucumbers, particularly in the larger sizes (Fleming et al., 1973a), is a source of serious economic loss to the pickle industry. The primary cause for this type of spoilage has been shown to be due to the production of gases, primarily CO_2, in the fermentation brines (Etchells et al., 1968). Microorganisms that have been associated with gaseous fermentations of commercially brined cucumbers include yeasts (Etchells and Bell, 1950b; Etchells et al., 1952, 1953), coliform bacteria of the genus Aerobacter (Etchells et al., 1945) and hetero-fermentative lactic acid bacteria (Etchells *et al*., 1968). More recently, however, Fleming *et al*. (1973a,b) and Etchells *et al*. (1975) found that CO_2 which originates from the cucumber tissue itself, plus the small amount produced by the homofermentative lactic acid bacterium, *L. plantarum*, is sufficient to cause serious bloater damage.

The mechanism of bloater formation has been proposed by Etchells *et al*. (1968) and further investigated by Fleming *et al*. (1978b). Their findings showed that bloaters are formed by the liberation and expansion of dissolved gas in cucumber tissues.

The course and outcome of bloater formation during fermentations have been shown to depend on many factors, although not always in a predictable way. Improper mechanical harvesting and handling were shown to have significant effect on the formation of bloaters (Marshall *et al*., 1971a,b, 1972a; Sarig *et al*., 1975). Sneed and Bowers (1970) reported that as fruit firmness and skin toughness increased the percentage of balloon bloating increased. Pack-out ratio (cucumber:brine), brining depth and fermentation temperature have been demonstrated to affect bloater damage (Etchells *et al*., 1975; Fleming *et al*., 1977). Fermentation temperature and brine strength affect CO_2 solubility in the brine and thus may influence bloater damage (Quinn and Jones, 1936; Fleming *et al*., 1975). Effect of cucumber size and brine composition (Fleming *et al*., 1973a; Niemela and Laine, 1975) as well as cucumber maturity

(Pederson and Albury, 1962) on bloater development were reported by several workers. The relationship between fermentation time and bloater-type damage of brine cucumbers was also elucidated by Shoup et al. (1976).

In the 1950's, when bloater damage was believed to be primarily due to fermentative yeasts, several researchers reported means of controlling yeast growth by the addition of sorbic acid (Phillips and Mundt, 1950; Costilow et al., 1955, 1957; Costilow, 1957). However, the etiology of bloater development has led investigators to recommend a controlled fermentation process to commercial briners to alleviate many problems of bloater damage in brine stock (Etchells et al., 1973b). Removal of CO_2 by nitrogen purging soon after the tanks are filled reduced or eliminated bloater damage (Fleming et al., 1975). The principle of purging was explained by Fleming (1979). Brine circulation, particularly if started sooner, may also reduce build-up of CO_2 (Etchells et al., 1975).

Since nitrogen purging is an expense to the brining operation, interest has developed in establishing the maximum tolerance or critical level of CO_2 for bloater damage. Etchells et al. (1973b) recommended that the dissolved CO_2 be maintained below 20 mg/100 ml brine. However, this critical concentration is variable and is influenced by fermentation temperature and cucumber size (Fleming et al., 1973a; Fleming, 1979).

Purging CO_2 from brines with air also prevents bloater formation, but has not been recommended because of potential adverse effects on quality factors of the cucumbers such as texture and appearance (Fleming et al., 1975).

Storing cucumbers in salt-free acidulant solutions to inhibit the primary microbial sources of bloater damage was reported by Shoup et al. (1975). Reduction of bloater damage was observed when acetic acid was used alone at a higher rate (4.4% titratable acidity).

Marshall et al. (1973) proposed that cucumbers be sorted by density. Cucumbers that sink could be placed in brine while floaters would be processed immediately into fresh-pack pickles. They reported that the frequency of balloon bloating among sinkers was half or less than that of floaters; however, the correlation was much lower for overall bloating. The specific gravity of the sorting solution would likely have to be varied with each change in variety, grade size, or growing location (Marshall, 1975; Marshall et al., 1975b).

Enzymatic Softening

One of the spoilage problems that has confronted the industry and caused severe losses annually is that of enzymatic softening of cucumbers during brine fermentation and storage. It has been reported that the softening of cucumbers brined under commercial conditions is primarily the result of the hydrolytic action by a system similar in

action to polygalacturonase and another system pectinesterase (Bell et al., 1950, 1951). Also it has been reported that cellulolytic enzyme systems are present in curing brines and may contribute to the total softening action (Bell et al., 1955; Etchells et al., 1955a).

Continued studies on this problem definitely implicated filamentous fungi as the actual cause of softening spoilage. Further, the hydrolytic enzymes, pectinase and cellulase, of fungal origin were shown to be introduced into the curing brines chiefly by way of fungus-laden flowers that remain attached to the cucumbers, and to a lesser extent by fungal enzymes on the fruit itself. The enzymes are produced in the flowers prior to entering the brine and not by fungal growth during the fermentation (Etchells et al., 1958a; Raymond et al., 1959). This work also demonstrated that the maximum concentration of softening enzymes diffused out of the flowers and into the brine within 24-48 hours after the vats were filled.

Mechanical removal of flowers from cucumbers or draining off the brine after 36 hours are procedures recommended (Etchells et al., 1955b) and used by the pickle industry to reduce the softening enzymes in the brine.

The use of specific, naturally occurring, non-toxic substances as inhibitors for the softening enzymes was studied. Scuppernong grape leaves (Etchells et al., 1958b) and Sericea (Bell et al., 1965) were found to effectively inhibit pectinolytic and cellulolytic enzymes in cucumber fermentations. However, neither of them is available or accepted for commercial use.

Studies have shown that as purified pectinolytic enzymes were incorporated into cucumber brines of increasing strength, firmness increased as brine strength increased (Etchells and Jones, 1951; Bell and Etchells, 1961).

Calcium is used extensively by the food industry to enhance firmness of several processed products. Fleming et al. (1978a) found that calcium in fermentation brine was beneficial to the firmness of sliced and small whole pickles. Buescher et al. (1979) observed the efficiency of $CaCl_2$ on retarding softening of cucumbers during fermentation and in the presence of high polygalacturonase activity. Their data indicated that softening was greatly retarded when $CaCl_2$ (0.1M) was present in either high (9%) or low (4.5%) brine concentration.

Fresh-Pack Pickles

Fresh-pack pickle products have proven very popular with the consumer because they retain much of the characteristic crispness and attractive appearance of the natural cucumber (Etchells and Jones, 1951).

A number of quality factors in fresh-pack pickles such as texture, appearance, flavor, and internal damage, have been studied as a function of such manufacturing variables as conditions of holding, heat treatment, and storage.

Effect of Holding

Dirty, scuffed-appearing skin areas and an unnatural color have been attributed to rough handling; however, holding cucumbers improperly also has been observed to cause quality deterioration. The effect of holding cucumbers on the quality of the whole fresh dill pickles was examined by Cook *et al*. (1957). Cucumbers harvested from a commercial field were divided into ten representative lots. One lot was packed immediately (as a control), the others were held at temperatures of 4.4, 15.6, and 26.7°C for 24, 48, and 72 hours, respectively, before being packed as pasteurized, fresh whole pickles. The quality of the pickles was evaluated on the basis of appearance, color, and texture. Pickles made from cucumbers held for 24 hours at any of the three temperatures were acceptable, but inferior in quality to the controls. Increasing the holding time and temperatures of the cucumbers resulted in further uniform deterioration of quality. At 72 hours, the only acceptable finished pickles were those held at 4.4°C. They concluded that the relationships of the measured pickle quality factor with holding times and temperatures of the raw material were linear.

Another study conducted by Esselen and Anderson (1956) included holding cucumbers at 2°C and at room temperatures for 0 to 16 days prior to packing. They observed that prolonged holding of the raw cucumbers, even under

refrigeration, resulted in off-flavors and poor texture in fresh-pack pickle spears. These changes appeared to increase to some extent during storage of the finished pickles. With the exception of the pickles made from cucumbers held longer than six days, the flesh of the pickle spears retained a good white "chalky" or opaque appearance during storage. It was also noted that the turbidity of the pickle brines, after storage for two months, increased with the holding time of the raw material.

Jones and Etchells (1950), Nicholas and Pflug (1962), and Fellers and Pflug (1965) found distinct crispness differences in fresh-pack pickles, depending on variety. Nicholas and Pflug (1962) also reported differences in firmness among varieties in regard to the time from harvest to packing, the quality generally decreasing with holding time.

Effect of Processing

It is important that when preservation is brought about by pasteurization, the final products must not only remain free of spoilage and possible off-flavors resulting from residual peroxidase but also free of undesirable physical and flavor changes which may be brought about by overheating.

A number of publications have dealt with the manufacture of high-quality fresh cucumber pickles (Etchells, 1938; Etchells and Goresline, 1940; Etchells and Ohmer,

1941; Etchells and Jones, 1942, 1943b, 1944). In these studies it was found that controlled pasteurization at an internal-product temperature of 73°C (165°F) for 15 minutes or 71°C (160°F) for 20 minutes, followed by prompt cooling to below 38°C (100°F), was successful in obtaining a high-quality product from the standpoint of freedom from spoilage as well as retention of most original firmness during several months of storage. Etchells and Ohmer (1941) and Etchells and Jones (1942) observed that only the heat resistant, spore-forming bacteria survived this pasteurization procedure and that these showed little or no increase during storage.

Data from Nicholas and Pflug's (1961) work on over- and under-pasteurization of fresh-pack pickles, using several processing temperatures and times, indicated that an equivalent process time F_{180}^{18} of about 2 minutes resulted in pickles of maximum firmness. Firmness decreased as equivalent process time increased. Internal damage, largely carpel separation, was evident when the temperature in the container exceeded 82°C (180°F). Damage was proportional to maximum temperature, regardless of the overall equivalent process time. In all treatments, firmness was significantly lower for the heat-processed pickles than for the raw cucumbers.

Contrary to the results of earlier pasteurization studies and the work of Nicholas and Pflug (1961), Esselen *et al.* (1951) and Esselen and Anderson (1957) could find no

softening effect due to pasteurization times up to 40 minutes at 82°C (180°F) or to varying ingoing brine acidities.

Many studies have demonstrated that peroxidase enzyme activity in fresh-pack pickles is associated with the development of off-flavor and off-odor during storage (Nebesky _et al_., 1950, 1951; Anderson _et al_., 1951; Labbee and Esselen, 1954).

Esselen and Anderson (1957) indicated that pasteurization times of 25 to 30 minutes at 82°C (180°F) were adequate to prevent or reduce the presence of off- or stale-like flavors. They concluded that pasteurization procedures for these products much not only be adequate to destroy potential spoilage microorganisms but must also inactivate enzymes which might otherwise cause off-flavor development and softening.

Influence of cover-brine content on the pickle quality has been studied by several workers. Etchells _et al_. (1972) investigated the effect of alum on fresh-pack dill pickles. They found that alum caused a reduction in firmness of the product during storage. This finding was contrary to the previously widely accepted belief that alum functions as a firming agent in pickle products. In studying the influence of different organic acids on the firmness of fresh-pack pickles, Bell _et al_. (1972) reported that acetic acid (0.6-1.5%) was the best acidulant precluding the use of lactic, citric, malic, or oxalic in the manufacture of fresh-pack pickles. Pangborn _et al_. (1958) found that the addition of

2.0% sucrose improved the flavor of processed dill pickles. In a subsequent study Pangborn et al. (1959) further indicated that the sample containing 2.0% sucrose was the most desirable in flavor, texture, color, and overall acceptability. Jelen and Breene (1973) also reported that texture can be improved by adding sugar (sucrose or lactose) in cover-brine. The role of sugar in improving texture is not clear.

Monroe et al. (1969) reported on the influence of acetic acid (range 0.20-1.00%) and internal-product pasteurization temperatures (range 49-93°C) on physical, chemical, and microbial changes in fresh-pack dill pickles. They concluded that temperatures in the range of 71-76.5°C with an equilibrated acidity of 0.60% acetic acid or greater, produced pickles of good quality.

Effect of Storage

The role of warehouse temperature in loss of firmness in fresh-pack pickles was recognized as a factor of economic significance by Nicholas and Pflug (1960). They reported that deterioration during storage of fresh cucumber pickles was found to be a function of temperature, the rate of degradation being faster at higher temperatures. Products stored at 5°C remained in excellent condition in all respects throughout the test period of 388 days. They recommended that an average effective temperature of 22°C or less should be maintained to obtain good product quality for the entire storage period.

Pangborn *et al*. (1959) and Fellers and Pflug (1965) found that the pickles softened considerably with increasing time and temperature of storage except when maintained at temperatures lower than about 22°C. The former authors further reported that refrigeration temperature of 1°C, however, caused an undesirable color change which had an inverse relationship to softening, suggesting that apparent color changes were alterations in cellular structure rather than changes in hue. Temperatures of 21 and 30°C resulted in smaller quality changes than did temperatures of 1 and 37°C. The lowest quality was observed after 16 weeks of storage with little subsequent deterioration.

Textural Characteristics of Cucumber Products

Factors Affecting Texture

As has been reviewed, the texture of cucumber products is affected by various factors involved from harvest through processing to storage.

Damage due to impacts during harvesting, handling, and shipping is a major texture-related problem encountered with fresh cucumbers and this may lead to different types of quality reductions in processed products (Marshall *et al*., 1972b; Heldman *et al*., 1976). Prolonged holding time as well as improper holding conditions also resulted in undesirable softening of cucumbers (Esselen and Anderson, 1956; Fellers and Pflug, 1967).

Soft centers and bloater damage are other texture-related problems that are especially serious in brine fermentation and storage of large cucumbers. The advent of mechanical harvesting, which favors harvest of large sizes, has encouraged researchers to investigate solutions to these problems. For instance, seedless pickles developed by Baker et al. (1973) offer the advantage over the conventional seeded varieties since they are more adaptable to mechanization and fruits remain firm during seed maturation. The controlled fermentation procedure introduced to the industry by Etchells et al. (1973b) is another example.

Texture of salt-stock cucumbers can be affected by pre-processing and processing conditions (Fleming et al., 1978a); by brine constituents such as calcium chloride (Fleming et al., 1978a; Buescher et al., 1979), and organic acids (Shoup et al., 1975); and, of course, by the techniques applied throughout the whole process period.

Crisp texture of the fresh-pack cucumber pickles is the most important quality characteristic. Although heat processing reduced the firmness of pickles (Nicholas and Pflug, 1961), previous publications (Etchells and Jones, 1944; Esselen and Anderson, 1957) have pointed out that the successful manufacture of a quality-type of fresh-pack pickles can be achieved by controlled pasteurization of proper temperature and time followed by prompt cooling. Appropriate amount of acetic acid and sugar added in the cover-brine greatly improves texture (Bell et al., 1972; Jelen and Breene, 1973).

Evaluation of Texture

Cucumber products are judged or evaluated for quality by the consumer primarily on the basis of texture.

Methods. Texture of raw and processed pickles has commonly been evaluated objectively by various types of puncture testing devices. The hand-operated Magness-Taylor fruit pressure tester (FPT) has been the one most commonly used (Magness and Taylor, 1925). Measurement of firmness of genuine dill pickles (Jones et al., 1941a) appears to be the first reported application of the FPT to cucumber pickles. Jones *et al*. (1954) and Bell *et al*. (1955) devised firmness rating scales for salt-stock pickles based on FPT values. Similar rating scales from the FPT have since been routinely used by researchers in the textural evaluation of various cucumber products, including salt-stock pickles (Etchells *et al*., 1958b; Bell and Etchells, 1961; Bell *et al*., 1965), fresh-pack pickles (Monroe *et al*., 1969; Etchells *et al*., 1972; Nicholas and Pflug, 1960; Bell *et al*., 1972), and raw cucumbers.

Another puncture tester used in pickle texture studies was the mechanical recording pressure tester (MRPT) which was modified from the FPT by mounting a plunger tip in a machine that drew out a complete force-distance curve for the test (Pflug *et al*., 1960). By so doing, variability among results obtained by different operators was thus eliminated. Nicholas (1960), using pickles and other fruits as test samples, observed significant differences between FPT and MRPT results.

Breene et al. (1974) made a study of the important textural criteria affected during texture measurement of cucumber fruit with the FPT. Raw fruit of a firm and a soft cucumber cultivar were manually puncture tested with the FPT, and also with the FPT or only FPT tip mounted in the Instron Universal Testing Machine (UTM). Maximum forces for the UTM-FPT "skin-on" or "skin-off" combination were almost identical to the corresponding UTM-Tip forces, but distance travelled by the FPT was much greater than the tip. Puncture values for flesh only were 70-75% of those for intact fruit. Neither the cucumber size (2.54-6.35 cm diam.) nor the Instron test speed (5-50 cm/min) appreciably affected the puncture test values. Precision for hand-operated fruit pressure testers may be improved by using data from a single operator and penetrating the fruit slowly.

Marshall et al. (1975a) developed an instrumental method for the measurement of carpel suture strength in cucumbers. They found that the most acceptable measurement criterion for carpel suture strength is the peak force necessary to cause carpel suture separation. In their test, a cucumber cross-sectional slice 6 mm thick was placed on a slice support in the Instron Universal Testing Machine and a 0.476 mm diam. probe was passed through the slice at the intersection of the three carpel sutures. The percentage difference between the force required to separate the carpel

suture and the force required to pass through an artificially severed slice was established as a measurement of the sensitivity. Studies on variation due to slice location revealed that sensitivity was highest at the blossom end, but more convenient at the center of the fruit.

The application of Texture Profile Analysis (TPA) to demonstrate textural differences in cucumber products was introduced by Breene et al. (1972). They used the Instron Universal Testing Machine to determine seven TPA parameters in 24 cucumber cultivars chosen to encompass a wide range of genetic stocks. This method involves twice compressing, in the Instron, a 1 cm thick cucumber slice obtained from the cucumber midpoint to a thickness of 0.25 cm. Interpretation of the force-distance graphic response from this procedure provides an analysis which represents a quantitative indication of brittleness, hardness, total work, elasticity, cohesiveness, gumminess, and chewiness. The tendency for the seven parameters to parallel one another led these workers to suggest that cucumber texture might be adequately assessed by measuring one or more of three parameters: (1) brittleness, (2) hardness, and (3) total work. Breene et al. (1973) observed that with the exception of brittleness and cohesiveness, raw and brined fruit textural parameters were well correlated. Varieties rating high in raw fruit textural quality, indicated by high Instron TPA values, usually maintained a high quality rating after brining. Their findings supported the conclusion of

Sneed and Bowers (1970) that firmness and skin toughness measurements on green fruit were significantly correlated with the same measurements on brine stock.

Jeon _et_ _al_. (1973) were the first to statistically correlate TPA values of brittleness, hardness, and total work of compression with sensory responses as well as with the conventional FPT firmness to determine optimum texture testing procedures for raw cucumbers with and without skin. They found that all comparisons showed significant positive correlations. TPA values were well correlated with sensory tests. FPT firmness showed good correlations with sensory scores, as well as with TPA parameters. Therefore, they recommended continued use of the FPT for field purposes. However, it is not feasible for detecting small textural differences due to its low sensitivity and large operator variability.

Two similar studies (Jeon _et_ _al_., 1975a,b) were then designed to define optimum texture testing procedures for fresh-pack and salt-stock pickles using the same method as was developed by Jeon _et_ _al_. (1973). In general, they found good correlations in all comparisons except that in salt-stock cucumbers correlations were poorer between instrumental and sensory methods due largely to inordinately high sensory scores assigned to salt-stock of the slicing variety by all panelists.

Problems. Firmness, as measured by a puncture test, is still the predominant method of measuring textural quality of various fruits, including cucumbers. There needs to be a wider understanding of the multidimensional nature of the textural properties of fruit and the fact that firmness is only one of the characteristics that constitute texture (Bourne, 1979). The applications of TPA parameters in analyzing textural properties of cucumber products have been studied (Breene *et al*., 1972; Jeon *et al*., 1973, 1975a,b); however, methods designed for particular types of cucumber products such as fresh-pack cucumber spears have not yet been thoroughly investigated.

More knowledge of the chemical and biochemical factors that cause fruits to exhibit their characteristic textural properties (Van Buren, 1979) is desired for developing a better understanding of the sensory textural qualities of fruits and new objective measurements that correlate highly with sensory assessments.

MATERIALS AND METHODS

Source of Cucumbers

All the green-stock cucumbers used throughout the experiment were machine harvested and obtained either from experimental plots of the Department of Horticulture at Michigan State University or from the Green Bay Foods plant in Eaton Rapids, Michigan. Cucumbers harvested at Michigan State University were received in the laboratory the same day as harvested; cucumbers obtained from Eaton Rapids, however, were commercial run. Cucumbers were carefully selected for uniformity of shape and freedom from visible disease and mechanical damage prior to use in all experiments.

Experimental Design

The design and general protocol for a series of experiments are presented in this section.

Factorial Postharvest Study

This study was factorial for holding temperature and time. Green-stock cucumbers used were size 3B and were obtained from Michigan State University. Twenty pounds of the randomly selected cucumbers were filled into each of 26 5-gallon plastic pails. A sub-sample of about two pounds, segregated in cheesecloth, was then placed on top of each of these pails for analyses. Two pails of cucumbers were brined immediately (controls) and the remaining pails were held in duplicate at temperatures of 5, 20, and 30°C for 1, 2, 4, and 6 days, prior to salt brining and natural fermentation. All samples were brined at approximately the same time of day following the assigned post-harvest holding treatments.

The respiration rate of the fresh cucumbers held at different temperatures was determined daily by gas chromatograph throughout the holding period. Percent cucumber weight loss for each treatment condition was calculated from weight loss prior to brining.

Cucumbers in the sub-sample represented the green-stock of the same pail in each treatment. At the end of each holding time, the sub-sample was removed and cucumbers in the pail were brined. Five cucumbers were taken from each sub-sample and measured individually for length, width, specific gravity, and texture.

Following those measurements the cucumber samples were packed individually in plastic bags and stored at -20°C These frozen cucumber samples were then analyzed for pH, soluble solids, and total acidity.

The brine fermentation and storage of cucumbers required about two months, after which salt-stock pickles were assessed for the quality by visual evaluation and instrumental textural analyses.

Refrigerated Temperature Study

This study was designed as a 2 pickle size x 2 holding time x 2 temperature factorial experiment. Cucumbers were obtained from Michigan State University and approximately 21.5 pounds were randomly filled into each pail and an additional five pounds of cucumbers were maintained as a sub-sample.

For size 3B and 2B cucumbers, analysis of green-stock was done using five representative cucumbers from each sub-sample. Procedures used were the same as that described in the factorial postharvest study. Remaining cucumbers were prepared and packed immediately into two jars per replicate as fresh-pack pickle spears. These packed jars were then stored at 2°C. The quality of these processed pickles was determined by means of instrumental and sensory evaluations after nine months of storage.

At the conclusion of each holding treatment, only size 3B cucumbers were brined and evaluated as salt-stock.

To further evaluate quality changes in green-stock during refrigerated holding an additional experiment was designed. Size 3B cucumbers obtained from Eaton Rapids were held at 15°C for up to 3 days. Green-stock quality measurements previously described were performed daily on ten cucumbers.

Fluctuated Temperature Study

The cucumbers used in this study were size 3B and were obtained from Eaton Rapids. Procedure used in preparing the cucumbers and sub-samples was as described in the refrigerated temperature study. Six pails of cucumbers were prepared for this study; two replicate pails were immediately brined as a control. The remaining four pails were held in controlled temperature rooms (2 and 15°C) in duplicate for one day and then transferred to 28°C for an additional day prior to brining.

Fresh-pack pickle spears were prepared in four replicate jars for each treatment and evaluated with the same procedures used for the refrigerated temperature study. Methods for determining green- and salt-stock cucumber quality were those depicted in the factorial postharvest study.

Relative Humidity Study

In the relative humidity study size 3B cucumbers were used, which were subdivided into two independent studies. These two studies were designed essentially the same except for the source of cucumbers used. Cucumbers obtained from Michigan State University were used in study 1 while cucumbers obtained from Eaton Rapids were used in study 2.

For each of the relative humidity studies, cucumbers were held two days at two temperatures in three different levels of relative humidity. Control of the desired humidities was obtained in specially designed 5-gallon plastic pails. The pail was filled with a shallow layer of calcium sulfate ($CaSO_4$), RH = 0%; saturated sodium chloride (NaCl) solution, RH = 75%; or water (H_2O), RH = 100% (Rockland, 1960). Cucumbers of 2500 $\pm$ 30g were placed in a cylindrical basket made of galvanized wire mesh (0.33 cm square openings). The basket was then suspended in the pail and sealed with a cover as shown in Figure 1. A #2 rubber stopper was fixed onto a heavy wire, with two hooks on both ends, in such a way that it sealed the whole system by shutting off the hole.

The initial weight of cucumbers in each basket was recorded before the cucumbers were placed in the system. Weights of the cucumbers in each basket were recorded afterwards at 12-hour intervals. Percent weight losses of cucumbers were calculated. At the end of the 48 hour holding period, two jars of fresh-pack pickle spears were packed immediately from each basket while five representative cucumbers were evaluated for chemical composition and textural quality, using the same methods as described previously.

Brining and Processing Procedures

Brining and Fermentation

The fermentation pails and the brining procedures used in this experiment were in accordance with those

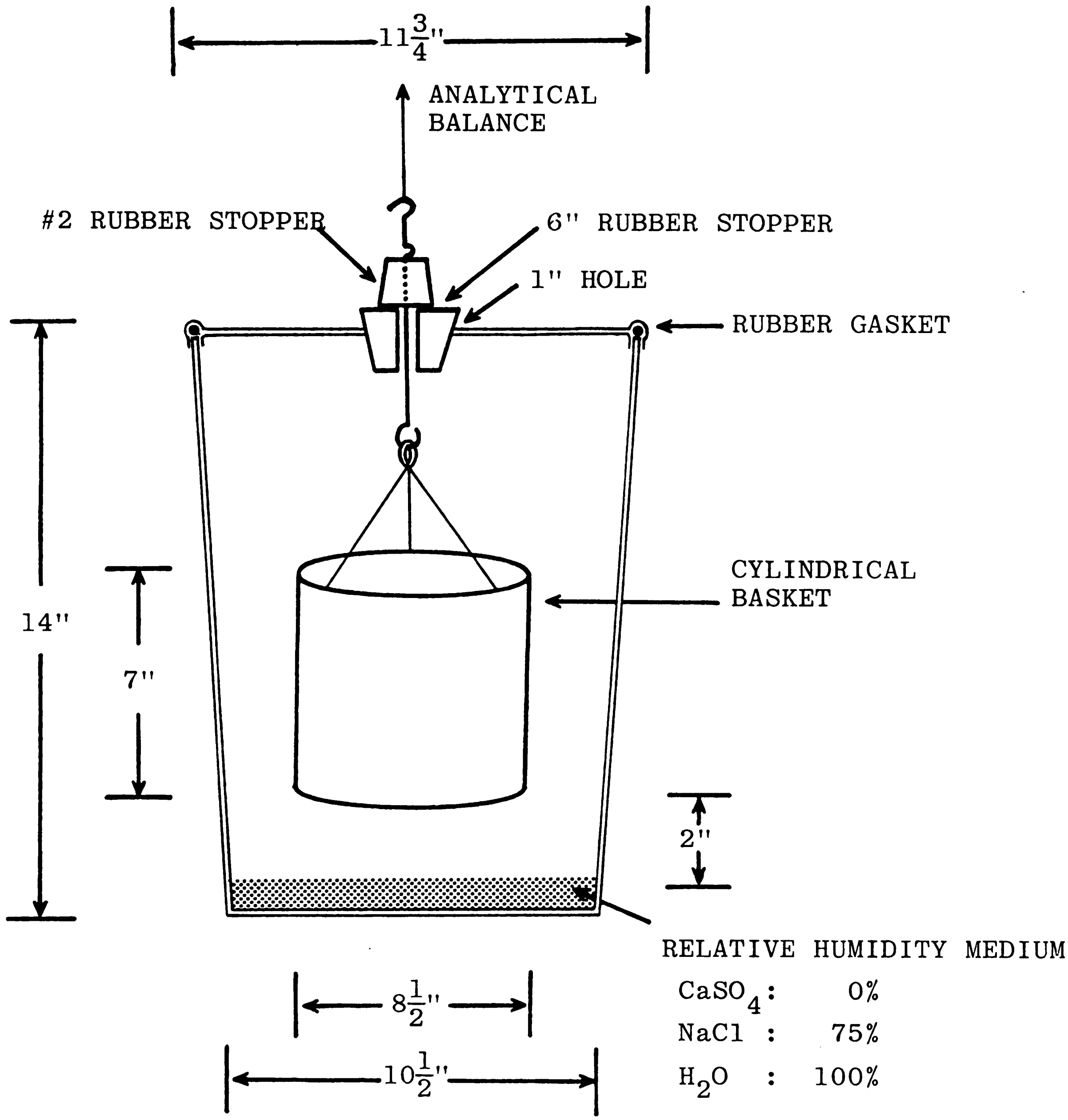

Figure 1. Design of controlled humidity 5-gallon plastic pail for holding cucumbers.

described and illustrated for laboratory use by Costilow and Uebersax (1978).

The system employed a large number of 5-gallon plastic pails which were designed to facilitate the nitrogen gas purging during the natural fermentation process.

The cucumbers in each pail were covered with a 40° salometer brine (10.6% w/w NaCl) containing 0.05% acetic acid. The acid was added to assure CO_2 solubility in the brine. Sufficient dry salt was added to the brine to equilibrate at about 25° salometer. The equilibrated brine strength was maintained until a 0.6% lactic acid concentration was attained at which time the brine strength was increased by 3° salometer weekly to a holding strength of 45° salometer. Brine strength or salt concentration was determined using a standardized hydrometer calibrated in degrees Salometer (Thomas Co., Philadelphia, Pennsylvania). Brine pH and total acidity (calculated as % lactic acid) were determined periodically by methods described by Etchells _et al_. (1964).

The nitrogen gas purging was started immediately after brining and the brine was then purged on schedule (15 minutes in mornings and 15 minutes in evenings) to accelerate salt circulation and to reduce CO_2 accumulation in the brine.

The cucumbers were allowed to undergo fermentation by the natural cucumber microflora for about two months. All treatments were replicated in duplicate pails.

Processing of Fresh-Pack Pickle Spears

Pickles were packed essentially as described by Esselen *et al*. (1951). Four jars from each treatment were prepared as follows. Cucumbers were washed with tap water and sliced lengthwise into four spears each and spear ends were cut square. Approximately 17 oz. of the spears (12-13 pieces) were hand-packed into 24 oz. glass jars of such height that the spears, when packed vertically, extended to the top of the jar, but left adequate head space. The spears were place-packed with the cut side next to the glass, exposing the inner surface. Jars were then brined with a commercially prepared brine containing vinegar, spice, and coloring and then sealed.

Pasteurization process was carried out in a steam blancher by heating the packed jars to an internal product temperature of 75°C for 10 minutes. At the end of the pasteurization time the jars were removed and tempered by continuously passing through a water bath (50°C) in 10 minutes, after which the jars were rapidly cooled in a cold water bath to 38°C or less. Cooled jars were then air dried, cased, and stored.

Analytical Methods

The following procedures were used to measure or evaluate the quality characteristics of the cucumber products as needed throughout the experiment.

Green-Stock Analysis

Length, Width, and Specific Gravity. Ten cucumbers from each treatment were measured for the parameters of length, width, and specific gravity. Length and width (cm) of cucumbers were determined by direct measurement using a plexiglass jig. Specific gravity, defined as weight (g)/ volume (ml), was obtained by measuring these two parameters for each cucumber. The weight was simply measured on a top-loading balance. Cucumber volume was determined by submerging in a 1000 ml graduated cylinder filled with 500 ml water and recording the volume displaced.

Texture. After the above measurements the cucumbers were prepared for texture evaluation as follows: two cross-sectional pieces 5/8" thick were cut from each cucumber tested, one from near the stem end and the other from near the blossom end. Two parallel sharp knives of fixed distance were designed to cut the pieces. Four consecutive cross-sectional slices 1/4" thick were cut from the central region of the cucumber. The device used to obtain cucumber slices of uniform thickness was essentially the same as that illustrated by Marshall *et al*. (1957a). Two pieces and four slices obtained from each cucumber were used for piece crush (side crush) and slice punch (center punch) measurements, respectively.

The Instron University Testing Machine (Model TTBM, Instron Corp., Canton, Massachusetts) equipped with a

Magness-Taylor fruit pressure tester tip (3/8" diameter) was used as the force detecting device. The crosshead speed was set at 10 cm/min and the chart speed was 20 cm/min. The chart full scale reading was 1 kg for slice punching and 10 kg for piece crushing. Peak force (kg) indicating the force required to cause carpel suture separation of a slice punched or flesh breakage of a piece crushed, was calculated for slice punching and piece crushing test. Work expressed in kg-cm was calculated for piece crushing test. Percent deformation expressing the crispness and firmness of the cucumber was also calculated for piece crushing test as follows:

$$\% \text{ Deformation} = \frac{\begin{array}{c}\text{Crosshead traveling distance}\\ \text{needed to cause a sharp crack}\\ \text{of cucumber flesh (cm)}\end{array}}{\text{Diameter of cucumber piece (cm)}} \times 100$$

The tested pieces and slices from individual cucumbers were collected, packed in polyethylene bags, and held at -20°C until further analyses were made.

<u>pH, Soluble Solids, and Total Acidity</u>. Weighed frozen cucumber samples ranging from 50 to 150 grams were placed in a Waring blender, and blended 1:2 with distilled water for three minutes.

pH was measured with a Beckman pH meter by inserting the glass electrode directly into the blended slurry.

A small portion of the slurry was filtered through a #2 Whatman filter paper and soluble solids content (°B) of the filtrate was determined with a Bausch and Lomb refractometer. Degree Brix values for the slurry were multiplied by 3 to correct for dilution.

Total acidity was measured by titration of 10 g slurry with 0.1 N NaOH to a pH 8.1 endpoint using a Beckman glass electrode pH meter. Percent acid expressed as malic was calculated as follows:

$$\% \text{ TA} = \frac{(\text{ml of NaOH})\ (0.1 \text{ N of NaOH})\ \left(\frac{\text{meq.wt. of malic acid}}{0.06703 \text{ g/meq}}\right)}{\left(\frac{10 \text{ g slurry x } 1/3 \text{ dilution factor}}{\text{fresh sample weight}}\right)} \times 100$$

Respiration Rate. Carbon dioxide production of the cucumbers was monitored in a continuous air flow-through system. Fresh cucumbers were placed in duplicate 2-quart Mason jars and maintained in dark temperature controlled cabinets. A constant flow rate of the air was maintained by capillary regulators. One ml gas samples were taken at entrance and exit ports of the sealed jars and analyzed using a Carle GC-8700 gas chromatograph equipped with a thermal conductivity detector (Carle Instruments, Inc., Fullerton, California). Respiration rates were calculated in the unit of ml CO_2/kg/hr as follows:

$$\text{ml } CO_2\text{/kg/hr} = \frac{\% \ CO_2}{100} \times \frac{\text{flow rate (ml/min)}}{\text{cucumber weight (g)}} \times \frac{60 \text{ (min/hr)}}{0.001 \text{ (kg/g)}}$$

Salt-Stock Analysis

Analysis of the brined-cured stock was made about two months after brining.

Visual Evaluation. Thirty brine-stock cucumbers out of each pail were cut longitudinally and evaluated for bloater damage and soft center development. The cut stock was categorized as no damage, honeycomb, lens, balloon, and soft center. Types of bloaters were determined according to the "Bloater Chart" of Etchells et al. (1974). A tally of total soft pickles among all classes was also recorded.

Texture. The Magness-Taylor fruit pressure tester (FPT) fitted with 7/16" diameter tip (D. Ballauf Mfg. Co., Washington, D.C.) was employed to evaluate salt-stock firmness (Bell et al., 1955). Firmness was measured as the force (lbs) required to puncture the wall of a pickle. Ten pickles were tested out of each pail. All the FPT measurements were made by the same operator.

The Instron which was used for green-stock texture evaluations was also used to evaluate salt-stock firmness. Preparation of this instrument was exactly the same as that described in green-stock analysis. Ten pickles from each pail were measured. Each was punctured once through the side wall in the center of the pickle.

<u>Fresh-Pack Pickle Analysis</u>

<u>Texture</u>. Two replicate jars of pickle spears from each treatment were randomly selected for texture analysis after refrigerated storage. These jars were equilibrated in room temperature overnight prior to evaluation. Each of five pickle spears from each of the two replicate jars were sheared with the flesh side up using a single blade mounted in the Instron. Areas (cm^2) of the shear surfaces were measured. The pickle shape which expresses the degree of curvature of the skin side of spears was defined using a three point scale. Peak force (kg) of the flesh and skin of each spear was determined from the first, second and third peaks as shown in Figure 2. The first peak taken from the distance range 0-1 cm indicated the force required to shear through the seed-flesh portion. The second peak taken from after the first peak, but before the third (highest) peak was considered to be associated with the force required to shear the skin edges and flesh. Number of the second peak, if more than one, for each spear shearing was recorded and the average of these peak forces was calculated for the second peak. The third peak indicated the force required to shear through the skin. Shear resistances (kg/cm^2) were also calculated.

The Instron crosshead speed and chart speed were set at 20 cm/min. The chart full scale reading was 20 kg. Each peak force value obtained is the mean of two individual shears

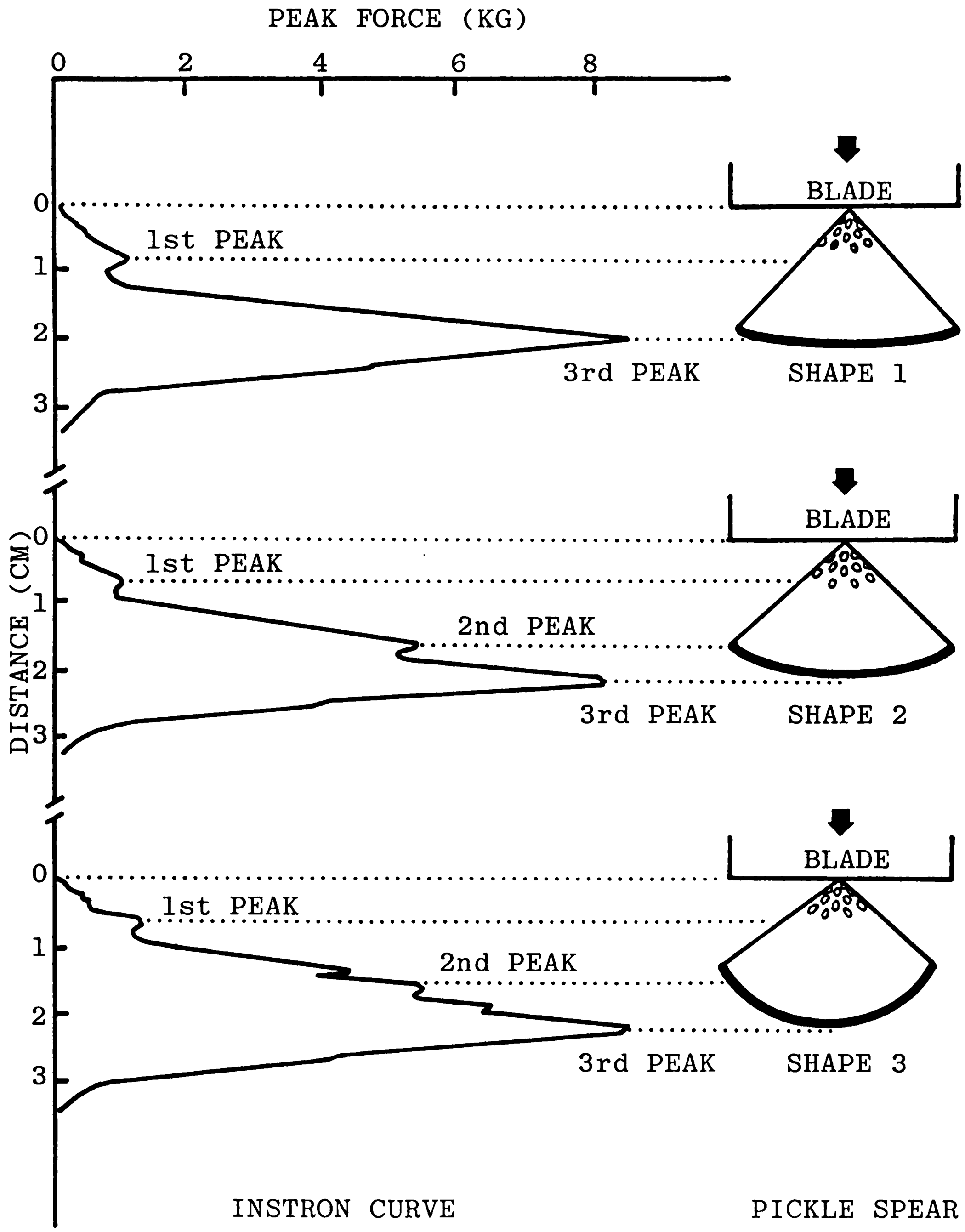

Figure 2. Typical force-distance curves for textural evaluation of crosscut fresh-pack pickle spears in relationship to the position of shear blade and pickle shape.

of each spear. For each spear, the shear positions were selected so that three sheared pieces were of equal length.

Sensory Evaluation. Two replicate jars from each treatment were used for sensory evaluation. Jars from three different studies were equilibrated in room temperature, coded with two digit numbers, and positioned randomly on benches prior to evaluation. Five trained panelists were selected from graduate students and staff of the Department of Food Science and Human Nutrition. Each of them was instructed to independently evaluate one spear out of each jar for flesh texture (depress between lips), skin texture (shear between incisors) and overall texture (chew and macerate in the mouth) according to a nine point hedonic scale (1 = extremely soft/mushy, 9 = extremely firm/crisp). All judgments were replicated by repeating the panel with the same panelists.

Statistical Analysis

The "Statistical Package for the Social Sciences" computer programs described by Nie *et al*. (1975) for use on the CDC 6500 computer operated by Michigan State University Computer laboratory was used to assist statistical analyses.

Multivariate analyses of variance and covariance were determined using subprogram ANOVA. Mean squares were reported after rounding. Single classification analyses of variance, Tukey mean separations, two tailed t-statistic

comparisons, and treatment trends were determined using subprogram ONEWAY.

Tukey separations were presented such that treatment which were not significantly different ($p \geq 0.05$) were indicated with like letters. Mean squares with significant F ratios and t statistics were reported with significant probability levels of $P \leq 0.05$ (*), $P \leq 0.01$ (**), and $P \leq 0.001$ (***). All mean values are reported plus or minus one standard deviation. Coefficient of Variation (CV) which expresses the standard deviation as a percent of the mean was calculated (Little and Hills, 1972).

The subprogram T-TEST was used to test the significance of the difference in the means of paired samples.

Pearson correlation coefficients (r) were determined from subprogram PEARSON CORR.

Scatter diagrams, regression equations, and correlation coefficients were determined using subprogram SCATTERGRAM.

RESULTS AND DISCUSSION

Factorial Postharvest Study

Green-Stock Analysis

Mean values and Tukey mean separations for chemical and physical characteristics of green-stock cucumbers held at various temperatures for up to six days prior to brining are presented in Table 1. Statistical analyses of these data are summarized in Tables 2 and 3. Size 3B cucumbers with average length of 11.2 $\pm$ 0.9 cm and width of 4.8 $\pm$ 0.3 cm were used for analyses.

Chemical Composition. Significant main effect differences in specific gravity were detected for holding temperature and time. Cucumbers held at higher temperatures had significantly lower specific gravity than those held at lower temperatures. Due to significant interactions, each temperature was analyzed in a single classification analysis. Generally the specific gravity of cucumbers held at different temperatures significantly linearly decreased with increasing holding time. This may be associated with the increased moisture loss of cucumbers during increased holding temperature and time without concomitant loss of tissue

Table 1. Chemical and physical characteristics of green-stock cucumbers held at 5, 20, and 30°C for up to six days prior to brining.[1]

Treatment Temp, Time (°C, day)		Chemical Composition[2] Specific Gravity	pH	Soluble Solids (°B)	Total Acidity (%)
Control		.9836 ± .0132^{def}	5.94 ± .07^{ab}	3.91 ± .48^{a}	.060 ± .007^{ab}
5	1	.9859 ± .0055^{ef}	5.78 ± .09^{a}	4.22 ± .35^{a}	.068 ± .007^{b}
	2	.9657 ± .0242^{cdef}	5.85 ± .08^{a}	4.41 ± .24^{a}	.066 ± .005^{b}
	4	.9686 ± .0070^{cdef}	5.90 ± .08^{ab}	4.08 ± .20^{a}	.064 ± .006^{ab}
	6	.9628 ± .0138^{cd}	5.87 ± .11^{ab}	3.81 ± .20^{a}	.066 ± .008^{b}
20	1	.9869 ± .0082^{f}	5.86 ± .08^{a}	4.18 ± .36^{a}	.063 ± .008^{ab}
	2	.9645 ± .0108^{cde}	5.93 ± .07^{ab}	4.35 ± .21^{a}	.066 ± .007^{b}
	4	.9309 ± .0164^{ab}	6.05 ± .16^{ab}	3.72 ± .43^{a}	.058 ± .010^{ab}
	6	.9145 ± .0295^{a}	6.61 ± .50^{c}	3.66 ± .19^{a}	.047 ± .015^{a}
30	1	.9834 ± .0101^{def}	5.85 ± .08^{a}	4.30 ± .14^{a}	.067 ± .007^{b}
	2	.9519 ± .0128^{bc}	5.95 ± .14^{ab}	4.17 ± .33^{a}	.069 ± .012^{b}
	4	.9134 ± .0379^{a}	6.31 ± .33^{bc}	3.69 ± .28^{a}	.055 ± .008^{ab}
	6	.9101 ± .0441^{a}	6.12 ± .29^{ab}	3.78 ± .47^{a}	.060 ± .010^{ab}

[1]Mean values and standard deviations (like letters within each column indicate no significant differences, $P \geq 0.05$).

[2]$n = 10$ (2 replicates/treatment x 5 cucumbers/replicate).

Table 1. (cont'd.)

Treatment Temp, Time (°C, day)		Textural Measure: Slice Punch[3] Force (kg)	Textural Measure: Piece Crush[4] Force (kg)	Textural Measure: Piece Crush[4] Work (kg-cm)	Textural Measure: Piece Crush[4] Deformation (%)	Respiration[5] Rate (ml CO_2/kg/hr)	Weight[5] Loss (%)
Control		.54 ± .11[a]	6.30 ± 1.40[c]	4.65 ± 1.40[a]	31.29 ± 6.94[a]	---	---
5	1	.36 ± .10[a]	6.14 ± 1.68[c]	4.81 ± 1.68[a]	29.04 ± 5.73[a]	6.31 ± 1.14[ab]	1.50 ± .35[abc]
	2	.41 ± .08[a]	6.50 ± 1.21[c]	5.29 ± 1.13[a]	29.76 ± 5.93[a]	6.28 ± 1.12[ab]	1.50 ± .35[abc]
	4	.41 ± .07[a]	5.65 ± .94[bc]	6.42 ± 2.37[a]	34.18 ± 4.50[ab]	7.92 ± 1.80[ab]	1.50 ± .35[abc]
	6	.37 ± .11[a]	6.04 ± 1.20[c]	6.12 ± 1.46[a]	34.24 ± 6.87[ab]	12.59 ± 0.47[abc]	1.88 ± .18[bcd]
20	1	.44 ± .11[a]	6.08 ± 1.66[c]	5.74 ± 1.87[a]	32.76 ± 7.38[a]	67.10 ± 11.33[cd]	1.38 ± .53[ab]
	2	.45 ± .08[a]	6.02 ± 1.49[c]	5.92 ± 1.68[a]	33.60 ± 8.40[a]	96.45 ± 21.71[def]	2.00 ± .71[bcd]
	4	.38 ± .08[a]	5.77 ± 1.34[bc]	6.33 ± 2.17[a]	35.45 ± 8.26[ab]	128.24 ± 26.22[ef]	3.25 ± .35[cde]
	6	.46 ± .30[a]	3.18 ± 1.67[a]	3.97 ± 3.49[a]	43.19 ± 6.46[bc]	77.75 ± 15.00[de]	4.63 ± .53[ef]
30	1	.32 ± .07[a]	5.18 ± .85[bc]	5.53 ± 1.19[a]	32.83 ± 6.41[a]	60.02 ± 9.05[bcd]	3.25 ± .35[cde]
	2	.43 ± .10[a]	5.73 ± 1.11[bc]	5.93 ± 1.84[a]	36.30 ± 7.79[abc]	68.88 ± 12.15[cd]	3.63 ± .18[def]
	4	.33 ± .13[a]	4.73 ± 1.86[abc]	4.45 ± 2.07[a]	36.52 ± 7.53[abc]	137.61 ± 29.02[f]	5.38 ± .53[fg]
	6	.39 ± .17[a]	3.96 ± 1.70[ab]	4.83 ± 2.35[a]	45.06 ± 5.66[c]	99.36 ± 55.92[def]	7.50 ± .71[g]

[3]n = 40 (2 replicates/treatment x 5 cucumbers/replicate x 4 slices/cucumber).
[4]n = 20 (2 replicates/treatment x 5 cucumbers/replicate x 2 pieces/cucumber).
[5]n = 2 (2 replicates/treatment).

Table 2. Analysis of variance of chemical and physical characteristics of green-stock cucumbers held at 5, 20, and 30°C for up to six days prior to brining.

Source of Variation	df	Chemical Composition			
		Specific Gravity	pH	Soluble Solids (°B)	Total Acidity (%)
		Mean Squares			
Main Effects	5	0.003***	0.16***	0.31***	0.00**
Temperature (Tp)	2	0.002***	0.15**	0.06	0.00*
Time (Tm)	3	0.004***	0.17***	0.48***	0.00**
Two-way					
Tp x Tm	6	0.000***	0.08**	0.03	0.00
Residual	12	0.000	0.01	0.04	0.00
% CV		0.000	1.90	4.77	0.00
		Planned Comparisons (t Statistics)			
5°C vs 20°C		7.96***	-4.66***	1.43	3.50**
5°C vs 30°C		11.47***	-3.70**	1.36	1.47
20°C vs 30°C		3.51**	.96	- .07	-2.03
5°C vs Control		- 3.01**	- .96	1.30	1.57
20°C vs Control		- 8.04***	1.99	.40	- .64
30°C vs Control		-10.26***	1.38	.44	.64
Expt. vs Control		- 7.63***	.86	.77	.56

Table 2. (cont'd.)

Source of Variation	df	Textural Measure: Slice Punch Force (kg)	Piece Crush Force (kg)	Piece Crush Work (kg-cm)	Piece Crush Deformation (%)	Respiration Rate (ml CO_2/kg/hr)	Weight Loss (%)
				Mean Squares			
Main Effects	5	.007	3.16***	.65	88.76***	8,880.04***	11.64***
Temperature (Tp)	2	.010	2.96**	.47	75.05***	18,686.77***	19.43***
Time (Tm)	3	.005	3.30***	.77	97.90***	2,342.22***	6.45***
Two-way							
Tp x Tm	6	.002	.98*	1.70	8.53	790.06*	1.20**
Residual	12	.003	.26	.90	5.31	238.14	0.21
% CV		13.69	9.46	17.39	6.54	24.08	15.16
			Planned Comparisons (t Statistics)				
5°C vs 20°C		-1.64	3.33**	.38	-3.92**	-11.35***	- 5.52***
5°C vs 30°C		.78	4.81***	1.04	-5.18***	-11.24***	-14.02***
20°C vs 30°C		2.42*	1.48	.66	-1.26	.11	- 8.50***
5°C vs Control		-3.33**	- .56	1.40	.29	.71	4.57***
20°C vs Control		-2.29*	-2.66*	1.16	2.76*	7.88***	8.06***
30°C vs Control		-3.82**	-3.60**	.74	3.56**	7.81***	13.44***
Expt. vs Control		-3.38**	-2.44*	1.18	2.37*	5.87***	4.33***

Table 3. One way analysis of variance of chemical and physical characteristics of green-stock cucumbers held at 5, 20, and 30°C for up to six days prior to brining.

Source of Variation	df	Mean Squares		
		5°C	20°C	30°C
Specific Gravity				
Time	3	.0002**	.0021**	.0024***
Linear	1	.0004**	.0063***	.0067***
Deviation	2	.0001*	.0000	.0003**
Quadratic	1	.0001*	.0000	.0004**
Deviation	1	.0001*	.0001	.0002*
Residual	4	.0000	.0001	.0000
% CV		.00	1.05	.00
pH				
Time	3	.0052	.2335**	.0815
Linear	1	.0102	.5641**	.1369
Deviation	2	.0027	.0683*	.0538
Quadratic	1	.0050	.1225*	.0420
Deviation	1	.0004	.0141	.0656
Residual	4	.0021	.0085	.0293
% CV		.78	1.51	2.83
Soluble Solids (°B)				
Time	3	.13*	.23*	.18
Linear	1	.24*	.48*	.42
Deviation	2	.07	.11	.05
Quadratic	1	.11*	.03	.02
Deviation	1	.03	.19	.08
Residual	4	.01	.03	.07
% CV		2.62	4.66	6.44
Total Acidity (%)				
Time	3	.00	.00	.0001
Linear	1	.00	.00	.0001*
Deviation	2	.00	.00	.0001
Quadratic	1	.00	.00	.0000
Deviation	1	.00	.00	.0001*
Residual	4	.00	.00	.0000
% CV		.00	.00	.00

Table 3. (cont'd.)

Source of Variation	df	Mean Squares		
		5°C	20°C	30°C
Slice Punch Force (kg)				
Time	3	.0015	.0025	.0058*
Linear	1	.0000	.0000	.0013
Deviation	2	.0022	.0038	.0081*
Quadratic	1	.0044	.0024	.0012
Deviation	1	.0000	.0052	.0150**
Residual	4	.0019	.0074	.0006
% CV		11.26	19.82	6.71
Piece Crush Force (kg)				
Time	3	.25	3.89**	1.13
Linear	1	.14	8.01**	2.18*
Deviation	2	.30	1.83*	.60
Quadratic	1	.00	3.19**	.87
Deviation	1	.61	.46	.33
Residual	4	.43	.12	.24
% CV		10.76	6.52	11.26
Piece Crush Work (kg-cm)				
Time	3	1.10	2.17	.90
Linear	1	2.56	2.39	1.29
Deviation	2	.37	2.06	.70
Quadratic	1	.31	3.22	.00
Deviation	1	.43	.89	1.40
Residual	4	.65	1.23	.81
% CV		13.68	20.17	17.38
Piece Crush Deformation (%)				
Time	3	15.58**	45.29	54.09*
Linear	1	40.02**	109.71*	136.07**
Deviation	2	3.36	13.09	13.10
Quadratic	1	.22	23.79	12.84
Deviation	1	6.50*	2.38	13.37
Residual	4	.64	11.93	3.36
% CV		2.51	9.53	4.86

Table 3. (cont'd.)

Source of Variation	df	Mean Squares		
		5°C	20°C	30°C
Respiration Rate (ml CO_2/kg/hr)				
Time	3	17.75**	1436.94*	2467.66
Linear	1	42.00**	406.02	3548.89
Deviation	2	5.63*	1952.40*	1927.04
Quadratic	1	11.07*	3187.21*	1088.34
Deviation	1	.10	717.58	2765.74
Residual	4	.75	189.02	524.65
% CV		10.48	14.88	25.01
Weight Loss (%)				
Time	3	.07	4.14*	4.64**
Linear	1	.13	12.10**	13.23**
Deviation	2	.04	.15	.34
Quadratic	1	.07	.28	.28
Deviation	1	.01	.03	.40
Residual	4	.10	.30	.23
% CV		20.00	19.37	10.33

volume. The specific gravity of cucumbers held at 5°C for up to four days, 20°C for up to two days, and 30°C for one day showed no significant differences from specific gravity measured immediately after harvesting. No significant differences were shown for cucumbers held at 20 and 30°C for four and six days. Marshall (1975) reported that specific gravity of cucumbers was an important factor in determining potential salt-stock damage. Results indicated that cucumbers with increased specific gravity produced more bloater damaged stock.

Significant differences in pH values were detected for all main effects and their interactions. Cucumbers held at 5°C had significantly lower pH values than those held at 20 and 30°C; however, no significant differences were found between cucumbers held at 20 and 30°C. pH of the control was not significantly different from that of any of the holding temperatures. Holding time showed no significant effect on the change of pH values at 5 and 30°C. A linear and quadratic increasing response was shown for holding time at 20°C.

No significant differences were shown in the soluble solids content of cucumbers among the control and all treatments; however, a significant decreasing trend was detected for holding time.

Significant differences in the total acidity of cucumbers were detected for holding temperature and time. Cucumbers held at 5°C had significantly higher percent total acidity

than those held at 20°C. No significant differences were detected between control and temperature treatments. Total acidity of cucumbers for 5 and 20°C each did not significantly differ among holding days; however, a linear decreasing response to holding time was shown when cucumbers were held at 30°C.

Textural Measure. The average values of slice punch forces obtained from four consecutive slices from blossom end to stem end showed no significant differences among treatments.

Each of the piece crush measures was obtained by taking the mean value from the blossom end and the stem end. These mean values were used to compare textural characteristics among environmental holding treatments.

Firm cucumbers required higher forces to cause flesh cracking or breakage than did soft cucumbers. Significant main effect differences in piece crush forces were detected for holding temperature and time and their interactions. No significant differences in piece crush forces were detected between the control and 5°C, or between 20 and 30°C. Cucumbers held at 20 and 30°C had significantly lower piece crush forces than did the control and 5°C. Piece crush forces decreased linearly with increased holding time for all temperatures except 5°C.

No significant differences were shown for piece crush work among treatments.

Piece crush deformation, indicating the distance necessary for the Instron crosshead to travel and cause a crack of the piece flesh, was expressed as percentage of piece diameter and was indicative of the degree of cucumber firmness. A firm cucumber was expected to have a smaller percent deformation due to its crispness. On the other hand, a soft cucumber may need a longer distance to cause a breakage or crack due to its limpness. Increased percent deformation therefore indicated a reduction in firmness. Significant differences were detected for both main effects. The values reported for each treatment were the average of piece crush deformation values from blossom and stem ends. Piece crush deformation of cucumbers did not significantly differ between control and 5°C, or between 20 and 30°C; however, significant differences were detected between these two groups. Percent deformation increased in a significantly linear trend for all temperatures as the holding time increased from one through six days, indicating cucumber softening.

Effect of location within the cucumber on textural evaluations by Instron punch and crush is shown in Figure 3. Slice 2 and 4 were shown to have significantly higher slice punch forces than did slice 1. The stem end had a higher piece crush force than did the blossom end, though not significant, indicating that the stem end may be firmer than the blossom end regardless of the treatments. Piece crush work showed that the stem end was significantly firmer in

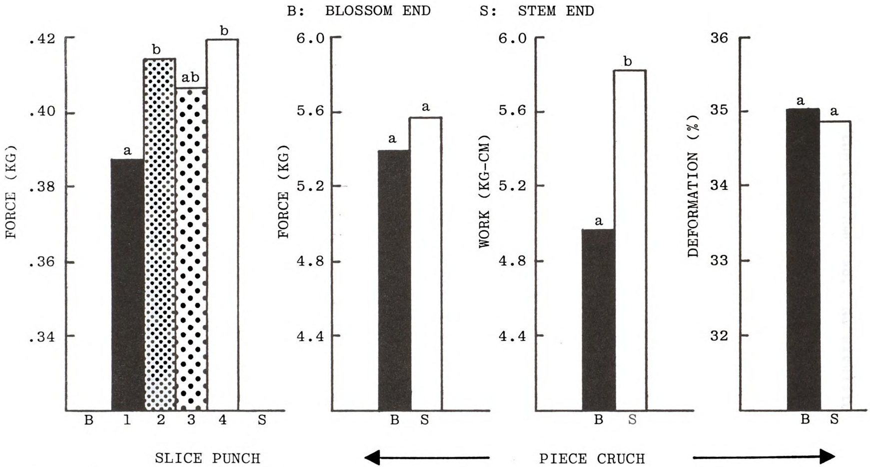

Figure 3. Effect of cucumber slice and piece locations on mean textural measure values (over temperature and time) for cucumbers held at 5, 20, and 30°C for up to six days prior to brining (like letters within each group indicate no significant differences, $P \geq 0.05$).

texture than the blossom end. No significant difference in percent deformation was shown between ends; however, the stem end showed a slightly lower value than that of the blossom end, which may indicate that cucumber stem ends have firmer texture than blossom ends.

Generally slice punch force was poorly correlated to any of the piece crush measurements in the evaluation of cucumber texture; however, piece crush force was significantly correlated to piece crush work ($r = 0.53^{**}$) and piece crush deformation ($r = -0.76^{***}$).

Respiration Rate. Significant differences in main effects for respiration rates were detected for both temperature and time and their interactions. Significant differences in respiration rates of cucumbers were detected between the control and 5°C, and 20 and 30°C; however, respiration rates did not differ within these groups. Cucumbers held at 5°C exhibited an increasing linear and quadratic response to increased holding time. The data supports the study by Hirose (1976a) such that respiration rates at chilling temperatures raised at first and then decreased during holding. A quadratic response trend was shown for cucumbers held at 20°C; however, no response to the time was found for those held at 30°C.

An increased respiration rate of cucumbers during holding results in a higher consumption of the sugar, thus, sugar may be limited for the curing process during fermentation.

Therefore, cucumbers with higher respiration rates are expected to yield salt-stock of poor quality.

Weight Loss. Significant differences in main effects for weight loss were detected for both holding temperature and time and their interaction. The significant interaction between temperature and time was associated with higher temperatures causing consistently higher weight losses than lower temperatures during holding periods. Cucumbers held at 20 and 30°C had significantly linear increases with increases in holding time.

An increase in weight loss indicates a decrease in moisture content which may cause shriveling of cucumbers and result in poor salt-stock quality.

Salt-Stock Analysis

Visual Evaluation. Mean values and Tukey mean separations for several visual defect classes of salt-stock cucumbers held at various temperatures for up to six days prior to brining are outlined in Table 4. Statistical analyses of these data are summarized in Tables 5 and 6.

Significant main effect differences for all classes, except lens defect, were detected for holding temperature and time and their interactions. One way analysis of variance indicated that cucumbers held at 5°C showed no significant differences in any class for holding time.

Table 4. Visual defect classification of salt-stock cucumbers held at 5, 20, and 30°C for up to six days prior to brining.[1]

Treatment Temp, Time (°C, day)		Defect Class (%)[2] No Damage	Honey-comb	Lens	Balloon	Soft Center	Total Soft[2] Among All Defect Classes (%)
Control		46.5 ± 19.1^{b}	36.5 ± 4.9^{d}	11.5 ± 16.3^{a}	5.0 ± 2.8^{a}	$0.0 \pm .0^{a}$	$0.0 \pm .0^{a}$
5	1	40.0 ± 18.4^{ab}	25.0 ± 2.8^{bcd}	25.0 ± 21.2^{a}	10.0 ± 4.2^{a}	$0.0 \pm .0^{a}$	3.5 ± 4.9^{a}
	2	40.0 ± 4.2^{ab}	42.0 ± 7.1^{d}	$13.0 \pm .0^{a}$	5.0 ± 2.8^{a}	$0.0 \pm .0^{a}$	$0.0 \pm .0^{a}$
	4	35.0 ± 7.1^{ab}	25.0 ± 11.3^{bcd}	32.0 ± 7.1^{a}	8.5 ± 12.0^{a}	$0.0 \pm .0^{a}$	1.5 ± 2.1^{a}
	6	41.5 ± 2.1^{ab}	23.5 ± 4.9^{abcd}	16.5 ± 4.9^{a}	18.5 ± 2.1^{a}	$0.0 \pm .0^{a}$	$7.0 \pm .0^{a}$
20	1	38.5 ± 12.0^{ab}	26.5 ± 4.9^{cd}	13.5 ± 4.9^{a}	21.5 ± 2.1^{a}	$0.0 \pm .0^{a}$	5.0 ± 2.8^{a}
	2	32.0 ± 7.1^{ab}	26.5 ± 9.2^{cd}	23.5 ± 4.9^{a}	18.5 ± 2.1^{a}	$0.0 \pm .0^{a}$	10.0 ± 9.9^{a}
	4	11.5 ± 2.1^{ab}	10.0 ± 4.2^{abc}	$13.0 \pm .0^{a}$	61.5 ± 12.0^{bc}	3.5 ± 4.9^{a}	36.5 ± 9.2^{b}
	6	$0.0 \pm .0^{a}$	3.5 ± 4.9^{ab}	15.0 ± 7.1^{a}	31.5 ± 12.0^{abc}	51.5 ± 16.3^{b}	$100.0 \pm .0^{d}$
30	1	33.5 ± 23.3^{ab}	36.5 ± 4.9^{d}	20.0 ± 14.1^{a}	10.0 ± 4.2^{a}	$0.0 \pm .0^{a}$	8.5 ± 12.0^{a}
	2	33.5 ± 9.2^{ab}	$23.0 \pm .0^{abcd}$	16.5 ± 4.9^{a}	26.5 ± 4.9^{ab}	$0.0 \pm .0^{a}$	10.0 ± 4.2^{a}
	4	$0.0 \pm .0^{a}$	11.5 ± 2.1^{abc}	11.5 ± 2.1^{a}	63.5 ± 23.3^{bc}	13.5 ± 19.1^{a}	63.5 ± 4.9^{c}
	6	$0.0 \pm .0^{a}$	1.5 ± 2.1^{a}	5.0 ± 7.1^{a}	5.0 ± 2.8^{a}	88.0 ± 7.1^{c}	$100.0 \pm .0^{d}$

[1]Mean values and standard deviations (like letters within each column indicate no significant differences, $P \geq 0.05$).

[2]Percent of each defect class out of 60 cucumbers (2 replicates/treatment x 30 cucumbers/replicate, $n = 60$).

Table 5. Analysis of variance of visual defect classification of salt-stock cucumbers held at 5, 20, and 30°C for up to six days prior to brining.

Source of Variation	df	Defect Class (%) No Damage	Honey-comb	Lens	Balloon	Soft Center	Total Soft Among All Defect Classes (%)
				Mean Squares			
Main Effects	5	1023.01***	529.29***	97.71	1163.73***	2357.14***	4842.71***
Temperature (Tp)	2	1148.79**	357.17**	144.04	1086.17***	1418.29***	4107.54***
Time (Tm)	3	939.15**	644.04***	66.82	1215.44***	2983.04***	5332.82***
Two-way							
Tp x Tm	6	231.74	119.33*	106.32	511.78**	894.79***	1223.65***
Residual	12	103.21	32.96	75.21	89.00	40.29	33.88
% CV		39.90	27.07	50.89	40.44	47.16	20.22
			Planned Comparisons (t Statistics)				
5°C vs 20°C		3.35**	4.31***	1.13	5.00***	-4.51***	-12.47***
5°C vs 30°C		4.03***	3.78**	1.77	-3.46**	-8.73***	-15.20***
20°C vs 30°C		.68	- .53	.63	1.54	-4.22***	- 2.73**
5°C vs Control		- .84	-1.70	1.35	.76	.0	.68
20°C vs Control		-2.96*	-4.42***	.63	3.93**	2.85*	8.57***
30°C vs Control		-3.39**	-4.09***	.23	2.95*	5.52***	10.29***
Expt. vs Control		-2.57*	-3.66**	.79	2.74*	3.00**	7.00***

Table 6. One way analysis of variance of visual defect classification of salt-stock cucumbers held at 5, 20, and 30°C for up to six days prior to brining.

Source of Variation	df	Mean Squares		
		5°C	20°C	30°C
No Damage (%)				
Time	3	16.13	638.33*	748.17
Linear	1	.03	1849.60**	1,795.60*
Deviation	2	24.18	32.70	224.45
Quadratic	1	21.13	12.50	.00
Deviation	1	27.23	52.90	448.90
Residual	4	102.63	49.75	157.25
% CV		25.89	34.41	74.87
Honeycomb (%)				
Time	3	154.13	274.13*	454.46**
Linear	1	46.23	731.03*	1,357.23***
Deviation	2	208.08	45.68	3.08
Quadratic	1	171.13	21.13	6.13
Deviation	1	245.03	70.23	.03
Residual	4	52.63	37.88	8.38
% CV		25.12	37.02	15.97
Lens (%)				
Time	3	146.46	48.17	84.83
Linear	1	4.23	3.60	250.00
Deviation	2	217.58	70.45	2.25
Quadratic	1	6.13	32.00	4.50
Deviation	1	429.03	108.90	.00
Residual	4	131.13	24.75	69.75
% CV		52.95	30.61	63.03
Balloon (%)				
Time	3	65.67	771.17*	1,402.17*
Linear	1	84.10	532.90	48.40
Deviation	2	56.45	890.30*	2,079.05*
Quadratic	1	112.50	364.50	2,812.50*
Deviation	1	.40	1416.10*	1,345.60*
Residual	4	43.75	74.50	148.75
% CV		62.99	25.90	46.46

Table 6. (cont'd.)

Source of Variation	df	Mean Squares		
		5°C	20°C	30°C
Soft Center (%)				
Time	3	.00	1272.17**	3,500.46***
Linear	1	.00	2496.40**	7,980.63***
Deviation	2	.00	660.05*	6,260.38**
Quadratic	1	.00	1152.00*	2,415.13**
Deviation	1	.00	168.10	105.63
Residual	4	.00	72.25	48.63
% CV		.00	61.82	26.19
Total Soft (%)				
Time	3	18.33	3812.79***	3,949.00***
Linear	1	14.40	9703.23***	10,758.40***
Deviation	2	20.30	867.58**	544.30*
Quadratic	1	40.50	1711.13**	612.50*
Deviation	1	.10	24.03	476.10*
Residual	4	7.25	47.63	46.75
% CV		89.75	18.22	15.03

Generally, the control, immediately brined, yielded the highest percentage of good quality pickles while very significant reductions in the percentage of good pickles were shown with increases in holding temperature. Significant linear decreases in the percentage of good pickles were shown with increases in holding time for 20 and 30°C.

Honeycomb and balloon defects showed similar results from all treatments. Percentage honeycomb and balloon did not differ significantly between control and 5°C, or between 20 and 30°C; however, significant differences were shown between these groups. At 20 and 30°C percent honeycomb defect showed a linear decreasing response to the days of holding. At 30°C percent balloon defect showed a quadratic response to the holding time.

In general, total bloater formation was found to increase with increased holding temperature and time. Previous discussion showed that holding cucumbers at high temperatures for long periods resulted in decreased specific gravity. Therefore, there may be an association between bloater defects and specific gravity of cucumbers. Further work in this area appears warranted. These data support that reported by Marshall (1975) who concluded that total bloater formation generally had an inverse relationship with specific gravity of cucumbers.

Percentage of soft centers and total softening showed an increased linear and quadratic response to increased holding time. Significant increases in softening were shown with increased temperatures. Percent total softening was highly significantly correlated to percent soft center (r = 0.90***).

Data showed that cucumbers held at 20 and 30°C for up to four or six days resulted in the greatest defects for salt-stock. It was apparent that the occurrence of bloater damage and softening in salt-stock cucumbers was caused by extended holding time at high temperatures.

Textural Evaluation. Mean values for center puncture tests by the FPT and Instron and statistical analyses of these data are presented in Tables 7 and 8. Significant differences were detected for holding temperature, time, and temperature by time interaction.

Significant reductions in the texture of cucumbers were found with increased holding temperature. Texture of pickles significantly decreased with increased holding time at 20 and 30°C; however, no significant differences for holding time were detected at 5°C.

A highly significant correlation (r = 0.98***) was shown between textural evaluations of pickles by FPT and Instron puncture tests. Either method will provide suitable measurement of resistance to puncture; however, the Instron showed less variability.

Results of this study indicate that postharvest holding conditions affect the chemical and physical composition of green-stock and subsequent salt-stock quality. Cucumbers

Table 7. Texture and analysis of variance of texture of salt-stock cucumbers held at 5, 20, and 30°C for up to six days prior to brining.

Treatment Temp, Time (°C, day)		Center Puncture Force: FPT (lb)	Center Puncture Force: Instron (kg)
		Mean Values and Standard Deviations[1]	
Control		19.39 ±2.67[b]	7.43 ±1.92[b]
5	1	19.02 ±2.63[b]	7.60 ±1.48[b]
	2	19.44 ±2.22[b]	7.84 ±1.61[b]
	4	18.95 ±1.54[b]	7.69 ±1.98[b]
	6	18.04 ±2.85[b]	8.40 ±1.56[b]
20	1	18.47 ±2.89[b]	7.57 ±0.87[b]
	2	17.80 ±3.57[b]	7.55 ±1.89[b]
	4	10.81 ±5.89[a]	4.93 ±2.71[a]
	6	---[2]	---
30	1	17.89 ±2.42[b]	7.21 ±2.45[b]
	2	16.66 ±3.21[b]	7.40 ±1.79[b]
	4	6.86 ±5.22[a]	3.95 ±3.13[a]
	6	---	---
Source of Variation	**df**	Mean Squares	
Main Effects	5	188.99***	28.11***
Temperature (Tp)	2	166.82***	25.16***
Time (Tm)	3	203.77***	30.07***
Two-way			
Tp x Tm	6	43.72***	9.88***
Residual	12	1.23	.16
% CV		8.12	6.90
		Planned Comparisons (t Statistics)	
5°C vs 20°C		12.79***	14.80***
5°C vs 30°C		15.36***	16.73***
20°C vs 30°C		2.57*	1.93
5°C vs Control		- .61	1.47
20°C vs Control		- 8.70***	- 7.89***
30°C vs Control		-10.33***	- 9.11***
Expt. vs Control		- 7.03***	- 5.56***

[1]Like letters within each column indicate no significant differences ($P \geq 0.05$), n = 20 (2 replicates/treatment x 10 pickles/replicate).
[2]Pickles were not measured due to excessive softening.

Table 8. One way analysis of variance of texture of salt-stock cucumbers held at 5, 20, and 30°C for up to six days prior to brining.

Source of Variation	df	Mean Squares		
		5°C	20°C	30°C
FPT (lb)				
Time	3	.69	146.97***	143.54***
Linear	1	1.12	388.75***	401.32***
Deviation	2	.47	26.08*	14.65*
Quadratic	1	.91	51.51**	15.96*
Deviation	1	.03	.65	13.34*
Residual	4	.56	2.00	1.11
% CV		3.98	12.04	10.21
Instron (kg)				
Time	3	.26	25.43***	24.15***
Linear	1	.52	64.24***	62.95***
Deviation	2	.13	6.02**	4.75**
Quadratic	1	.11	12.03***	8.53***
Deviation	1	.16	.01	.97*
Residual	4	.25	.13	.10
% CV		6.37	7.26	6.93

held at 5°C for up to six days showed firm texture, low respiration rates, minimum weight loss, and good quality stock after fermentation. Increasing postharvest holding temperatures and holding times prior to brining resulted in soft texture, high respiration rates, increased weight loss, and a decrease in salt-stock quality. Cucumber texture was generally greater at the stem end than at the blossom end. Salt-stock pickle defects (bloaters and soft centers) increased dramatically under high temperature/ long time holding periods.

Refrigerated Temperature Study

Green-Stock Analysis

Mean values and Tukey mean separations for chemical and physical characteristics of green-stock cucumbers stored at refrigerated temperatures for two and three days prior to brining are presented in Table 9. Statistical analyses of these data are summarized in Table 10. Size 3B cucumbers with average length of 12.3 $\pm$ 0.7 cm and width of 4.5 $\pm$ 0.2 cm and size 2B cucumbers with average length of 9.9 $\pm$ 0.7 cm and width of 3.5 $\pm$ o.3 cm were used for analyses.

Chemical Composition. Significant main effect differences in specific gravity were detected for holding time and cucumber size. Specific gravity of cucumbers consistently

Table 9. Chemical and physical characteristics of size 3B and 2B green-stock cucumbers held at 2 and 15°C for two and three days prior to brining.[1]

Treatment Temp (°C)	Time (day)	Specific Gravity	pH	Soluble Solids (°B)	Total Acidity (%)
		Chemical Composition[2]			
		Size 3B			
Control		$.9554 \pm .0076^{c}$	$6.05 \pm .07^{a}$	$3.90 \pm .00^{d}$	$.069 \pm .007^{c}$
2	2	$.9586 \pm .0083^{c}$	$6.06 \pm .09^{a}$	$3.72 \pm .21^{cd}$	$.060 \pm .006^{bc}$
	3	$.9516 \pm .0099^{bc}$	$6.06 \pm .08^{a}$	$3.57 \pm .17^{abcd}$	$.062 \pm .004^{c}$
15	2	$.9572 \pm .0123^{c}$	$6.24 \pm .11^{ab}$	$3.84 \pm .19^{cd}$	$.068 \pm .009^{c}$
	3	$.9526 \pm .0100^{c}$	$6.77 \pm .50^{bc}$	$3.66 \pm .40^{abcd}$	$.053 \pm .022^{abc}$
		Size 2B			
2	2	$.9430 \pm .0140^{abc}$	$6.76 \pm .19^{bc}$	$3.21 \pm .25^{a}$	$.043 \pm .007^{ab}$
	3	$.9203 \pm .0321^{ab}$	$6.70 \pm .17^{bc}$	$3.39 \pm .38^{abc}$	$.040 \pm .006^{a}$
15	2	$.9373 \pm .0130^{abc}$	$7.01 \pm .30^{c}$	$3.27 \pm .39^{ab}$	$.037 \pm .009^{a}$
	3	$.9120 \pm .0214^{a}$	$7.31 \pm .35^{c}$	$3.51 \pm .47^{abcd}$	$.035 \pm .012^{a}$

[1]Mean values and standard deviations (like letters within each column indicate no significant differences, $P > 0.05$).

[2]$n = 10$ (2 replicates/treatment x 5 cucumbers/replicate).

Table 9. (cont'd.)

Treatment Temp, Time (°C, day)		Slice Punch[3] Force (kg)	Piece Crush[4] Force (kg)	Piece Crush[4] Work (kg-cm)	Piece Crush[4] Deformation (%)
			Size 3B		
Control		$.46 \pm .05^{a}$	$4.95 \pm .57^{bc}$	4.46 ± 1.00^{ab}	31.29 ± 5.88^{ab}
2	2	$.50 \pm .06^{a}$	$5.72 \pm .61^{c}$	$4.93 \pm .85^{b}$	30.85 ± 4.80^{a}
	3	$.48 \pm .07^{a}$	$5.28 \pm .61^{bc}$	$5.18 \pm .92^{b}$	31.64 ± 6.80^{ab}
15	2	$.54 \pm .12^{a}$	$5.39 \pm .52^{bc}$	$5.67 \pm .96^{b}$	35.65 ± 7.98^{abc}
	3	$.52 \pm .17^{a}$	$4.24 \pm .55^{ab}$	3.81 ± 2.15^{ab}	36.13 ± 5.73^{abc}
			Size 2B		
2	2	$.65 \pm .15^{a}$	5.77 ± 1.05^{c}	5.76 ± 1.52^{b}	39.74 ± 10.31^{bcd}
	3	$.65 \pm .11^{a}$	5.52 ± 1.13^{bc}	4.87 ± 1.17^{ab}	41.31 ± 8.86^{cd}
15	2	$.73 \pm .20^{a}$	5.45 ± 1.29^{bc}	5.99 ± 2.31^{b}	39.36 ± 8.75^{abcd}
	3	$.30 \pm .34^{a}$	2.97 ± 1.46^{a}	2.40 ± 1.55^{a}	47.00 ± 10.24^{d}

[3]n = 40 (2 replicates/treatment x 5 cucumbers/replicate x 4 slices/cucumber).
[4]n = 20 (2 replicates/treatment x 5 cucumbers/replicate x 2 pieces/cucumber).

Table 10. Analysis of variance of chemical and physical characteristics of size 3B and 2B green-stock cucumbers held at 2 and 15°C for two and three days prior to brining.

		Chemical Composition			
Source of Variation	df	Specific Gravity	pH	Soluble Solids (°B)	Total Acidity (%)
		Mean Squares			
Main Effects	3	.001***	.883***	.179**	.001***
Temperature (Tp)	1	.000	.753***	.038	.000
Time (Tm)	1	.001*	.146*	.002	.000
Size (Sz)	1	.003***	1.749***	.497***	.002***
Two-way	3	.000	.072	.047	.000
Tp x Tm	1	.000	.196*	.000	.000
Tp x Sz	1	.000	.000	.000	.000
Tm x Sz	1	.000	.020	.141*	.000
Three-way					
Tp x Tm x Sz	1	.000	.007	.002	.000
Residual	8	.000	.026	.016	.000
% CV		.00	2.44	3.59	.00
		Planned Comparisons (t Statistics)			
Expt. vs Control (Size 3B)		.07	1.92	-2.18	-2.36*

Table 10. (cont'd.)

Source of Variation	df	Textural Measure: Slice Punch Force (kg)	Piece Crush: Force (kg)	Piece Crush: Work (kg-cm)	Piece Crush: Deformation (%)
		Mean Squares			
Main Effects	3	.03	3.12***	3.82**	118.37***
Temperature (Tp)	1	.01	4.51***	2.06	53.35**
Time (Tm)	1	.06	4.64***	9.31**	27.42*
Size (Sz)	1	.02	.22	.09	274.36***
Two-way	3	.04	1.02**	2.83*	9.35
Tp x Tm	1	.04	2.17**	5.77**	8.32
Tp x Sz	1	.03	.56	.66	4.00
Tm x Sz	1	.04	.33	2.06	15.75
Three-way					
Tp x Tm x Sz	1	.05	.59	.09	10.18
Residual	8	.02	.14	.46	4.69
% CV		25.71	7.45	14.03	5.74
		Planned Comparisons (t Statistics)			
Expt. vs Control (Size 3B)		.51	.75	.86	1.34

decreased with increased holding time. Size 3B (larger) cucumbers had significantly higher specific gravity than size 2B (smaller) cucumbers over holding temperature and time. No significant differences in specific gravity were detected for holding temperature.

Significant differences in pH values were detected for all main effects and temperature by time interaction. The pH increased significantly with increased holding temperature and decreased cucumber size. pH values of cucumbers did not differ significantly with increased holding time at 2°C; however, significant increases of the pH were obtained with increased holding time at 15°C.

Significant differences in soluble solids content were detected for cucumber size and the interaction with temperature. Soluble solids content of size 3B cucumbers was significantly higher than that of size 2B cucumbers. Holding cucumbers at refrigerated temperatures for two or three days resulted in no significant differences in soluble solids content of cucumbers.

Only cucumber size was detected to have significant main effect differences for percent total acidity of cucumbers. Generally, large cucumbers had significantly higher percent total acidity than smaller cucumbers.

<u>Textural Measure</u>. No significant differences in slice punch forces were shown among treatments.

Significant differences in piece crush forces were shown for temperature, time, and temperature by time interaction. Piece crush forces decreased significantly with increased holding temperature and time.

Significant main effect differences for piece crush work were detected for holding time and temperature by time interaction. A significant decrease in piece crush work was found with increased holding time for size 2B cucumbers held at 15°C. Piece crush work was significantly less for holding in 15°C than in 2°C for cucumbers held up to three days prior to brining.

Significant differences in piece crush deformation were detected for all main effects. Percent deformation increased significantly with increased temperature and time but decreased significantly with increased cucumber size.

Effect of location within the cucumber on textural evaluations by the Instron is illustrated in Figure 4. Slice punch force increased from blossom end to stem end. Significant differences were detected between slice 1 and both 3 and 4 and also between slice 2 and 4.

Piece crush force as well as piece crush work showed that texture of the stem end was significantly firmer than that of the blossom end. Percent deformation showed a non-significant decrease from blossom to stem end, indicating a firmer texture at the stem end. In regard to the texture evaluation of green-stock, slice punch force was significantly correlated to piece crush force (r = 0.69***) and piece crush

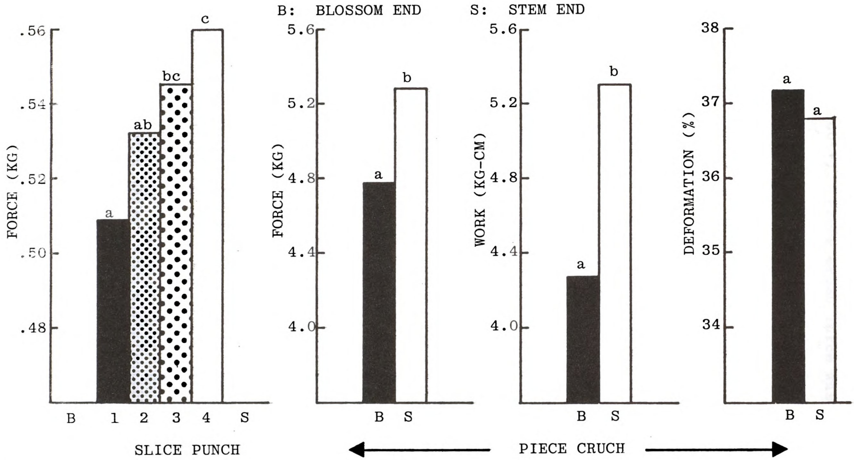

Figure 4. Effect of cucumber slice and piece locations on mean textural measure values (over temperature, time, and size) for size 3B and 2B cucumbers held at 2 and 15°C for two and three days prior to brining (like letters within each group indicate no significant differences, $p \geq 0.05$).

work (r = 0.60**). Piece crush force was significantly correlated to piece crush work (r = 0.87***) and piece crush deformation (r = -0.50*).

Salt-Stock Analysis

Visual Evaluation. Mean values and Tukey mean separations for visual defect classification of size 3B salt-stock cucumbers held at refrigerated temperatures for two and three days prior to brining are presented in Table 11. Statistical analyses of these data are summarized in Table 12.

None of the defect classes examined showed significant differences among treatments. The control remained the highest percentage of good pickles compared to any other treatment. Cucumbers held at 15°C for three days were found to result in the highest percentage of balloon type damage among all treatments. Percent total softening was significantly correlated to percent soft center (r = 0.74**).

Textural Evaluation. Mean values for texture evaluated by FPT and Instron and statistical analyses of these data are presented in Table 13. No significant differences were shown for the FPT and Instron force values among treatments. FPT force values were significantly correlated to Instron force values (r = 0.70*).

Table 11. Visual defect classification of size 3B salt-stock cucumbers held at 2 and 15°C for two and three days prior to brining.[1]

Treatment Temp, Time (°C, day)		Defect Class (%)[2] No Damage	Honey-comb	Lens	Balloon	Soft Center	Total Soft[2] Among All Defect Classes (%)
Control		70.0 ± 9.9^a	20.0 ± 18.4^a	10.0 ± 9.9^a	$0.0 \pm .0^a$	$0.0 \pm .0$[3]	$0.0 \pm .0^a$
2	2	60.0 ± 4.2^a	20.0 ± 4.2^a	15.0 ± 7.1^a	5.0 ± 7.1^{ab}	$0.0 \pm .0$	$0.0 \pm .0^a$
	3	58.0 ± 7.1^a	28.5 ± 16.3^a	13.5 ± 9.2^a	$0.0 \pm .0^a$	$0.0 \pm .0$	$0.0 \pm .0^a$
15	2	$53.0 \pm .0^a$	40.0 ± 4.2^a	5.0 ± 2.8^a	1.5 ± 2.1^a	$0.0 \pm .0$	$3.0 \pm .0^a$
	3	55.0 ± 2.8^a	$0.0 \pm .0^a$	23.5 ± 4.9^a	18.5 ± 2.1^b	$3.0 \pm .0$	10.0 ± 9.9^a

[1]Mean values and standard deviations (like letters within each column indicate no significant differences, $P \geq 0.05$).
[2]Percent of each defect class out of 60 cucumbers (2 replicates/treatment x 30 cucumbers/replicate, n = 60).
[3]Tukey mean separations are not presented due to no within variance.

Table 12. Analysis of variance of visual defect classification of size 3B salt-stock cucumbers held at 2 and 15°C for two and three days prior to brining.

Source of Variation	df	Defect Class (%): No Damage	Honey-comb	Lens	Balloon	Soft Center	Total Soft Among All Defect Classes (%)
				Mean Squares			
Main Effects	2	25.00	266.13	72.25	92.25	4.50	54.50
Temperature (Tp)	1	50.00	36.13	.00	112.50	4.50	84.50
Time (Tm)	1	.00	496.13	144.50	72.00	4.50	24.50
Two-way							
Tp x Tm	1	8.00	1176.13*	200.00	242.00*	4.50	24.50
Residual	4	19.00	75.13	41.75	14.75	.00	24.50
% CV		7.74	39.17	45.34	61.45	.00	152.30
		Planned Comparisons (t Statistics)					
Expt. vs Control		-2.89*	.24	.74	2.30	---[1]	.93

[1] t Statistic is not computed due to no within variance.

Table 13. Texture and analysis of variance of texture of size 3B salt-stock cucumbers held at 2 and 15°C for two and three days prior to brining.

Treatment Temp, Time (°C, day)		df	Center Puncture Force: FPT (lb)	Center Puncture Force: Instron (kg)
			Mean Values and Standard Deviations[1]	
Control			20.27 ± 2.81[b]	8.11 ± 1.39[a]
2	2		19.27 ± 3.35[ab]	7.89 ± 1.05[a]
	3		20.62 ± 1.69[b]	8.12 ± 1.49[a]
15	2		19.78 ± 2.87[ab]	8.17 ± 2.11[a]
	3		16.10 ± 3.49[a]	6.93 ± 2.14[a]
Source of Variation		df	Mean Squares	
Main Effects		2	5.28	.47
Temperature (Tp)		1	7.80	.42
Time (Tm)		1	2.76	.51
Two-way				
Tp x Tm		1	12.75*	1.08
Residual		4	1.11	.40
% CV			5.55	8.09
			Planned Comparisons (t Statistics)	
Expt. vs Control			-1.76	-.74

[1]Like letters within each column indicate no significant differences ($P \geq 0.05$), n = 20 (2 replicates/treatment x 10 pickles/replicate).

Fresh-Pack Pickle Analysis

Mean values and Tukey mean separations for instrumental and sensory evaluations of texture of pickle spears held at refrigerated temperatures for two and three days prior to brining are presented in Table 14. Statistical analyses of these data are summarized in Table 15.

No significant differences were detected in the first peak forces among treatments.

Analysis of covariance showed that shear area of pickle spears did have significant effects on both the second and third peak forces of pickle spears. Significant main effect differences in the second peak forces were detected for holding time. The second peak force, generally, decreased with increased holding time. Significant differences in the third peak force were shown for cucumber size and the interaction with temperature. The third peak forces of pickles made from larger cucumbers were significantly higher than those of pickles made from smaller cucumbers. Holding temperature and time had no significant effect on the third peak force of spears within each cucumber size.

Pickle spears made from smaller cucumbers were judged to be significantly firmer in flesh texture than those made from larger cucumbers.

Significant main effects in skin texture scores were detected for holding temperature and cucumber size. Skin texture scores decreased with increased holding temperature

Table 14. Instrumental and sensory evaluations of texture of size 3B and 2B fresh-pack pickle spears held at 2 and 15°C for two and three days prior to brining.[1]

Temp, (°C,	Time day)	Instrumental Evaluation[2] Peak Force (kg) 1st	2nd	3rd	Sensory Evaluation[3,4] Flesh	Skin	Overall
				Size 3B			
Control		$.97 \pm .41^{a}$	4.75 ± 2.63^{ab}	13.50 ± 3.42^{c}	$5.90 \pm .91^{ab}$	$6.00 \pm .82^{ab}$	$6.40 \pm .97^{ab}$
2	2	$.89 \pm .31^{a}$	8.30 ± 2.38^{c}	13.37 ± 2.01^{c}	4.80 ± 1.38^{a}	6.15 ± 1.62^{ab}	6.70 ± 1.70^{b}
	3	$1.16 \pm .36^{a}$	6.22 ± 1.91^{abc}	11.89 ± 1.48^{bc}	5.95 ± 1.28^{ab}	$6.45 \pm .80^{b}$	7.15 ± 1.03^{b}
15	2	1.76 ± 1.89^{a}	7.42 ± 1.97^{bc}	13.46 ± 1.36^{c}	5.20 ± 1.48^{a}	6.35 ± 1.31^{b}	6.85 ± 1.27^{b}
	3	$1.75 \pm .66^{a}$	4.14 ± 3.74^{ab}	14.01 ± 1.79^{c}	5.55 ± 1.94^{ab}	4.40 ± 2.00^{a}	4.55 ± 2.06^{a}
				Size 2B			
2	2	$1.31 \pm .38^{a}$	4.44 ± 1.95^{ab}	9.69 ± 2.25^{ab}	$6.80 \pm .98^{ab}$	6.90 ± 1.02^{b}	$7.55 \pm .80^{b}$
	3	$1.58 \pm .40^{a}$	5.02 ± 2.26^{abc}	11.78 ± 1.89^{bc}	6.80 ± 1.84^{ab}	$7.10 \pm .88^{b}$	$7.60 \pm .57^{b}$
15	2	$1.76 \pm .51^{a}$	4.92 ± 2.44^{abc}	10.12 ± 1.70^{ab}	$7.50 \pm .91^{b}$	6.80 ± 1.16^{b}	$7.55 \pm .96^{b}$
	3	$1.49 \pm .39^{a}$	3.95 ± 1.69^{a}	7.74 ± 1.96^{a}	7.45 ± 1.52^{b}	6.35 ± 1.47^{b}	6.40 ± 1.73^{ab}

[1]Mean values and standard deviations (like letters within each column indicate no significant differences, $P \geq 0.05$).
[2]$n = 20$ (2 replicates/treatment x 5 pickles/replicate x 2 shears/pickle).
[3]$n = 20$ (2 replicates/treatment x 5 panelists/replicate x 2 tests/panelist).
[4]Nine = extremely firm/crisp.

Table 15. Analysis of variance of instrumental and sensory evaluations of texture of size 3B and 2B fresh-pack pickle spears held at 2 and 15°C for two and three days prior to brining.

		Instrumental Evaluation			Sensory Evaluation		
Source of Variation	df	Peak Force (kg) 1st	2nd	3rd	Flesh	Skin	Overall
				Mean Squares			
Covariate							
Shear Area	1	.60	100.88***	230.41***	---[1]	---	---
Main Effects	3	1.40	14.98	8.66*	22.35***	10.56***	15.35***
Temperature (Tp)	1	4.16*	16.42	2.83	2.28	9.11*	16.65**
Time (Tm)	1	.03	27.00*	.01	2.63	4.51	10.88*
Size (Sz)	1	.01	4.67	21.61**	62.13***	18.05**	18.53**
Two-way	3	.78	12.65	18.72***	2.01	4.74	7.39**
Tp x Tm	1	.83	10.02	9.07	.90	10.51*	19.50**
Tp x Sz	1	1.47	6.31	46.31***	2.28	1.25	1.95
Tm x Sz	1	.05	21.53	1.21	3.00	2.45	.70
Three-way							
Tp x Tm x Sz	1	.11	.00	38.87***	.70	3.20	3.00
Residual	71	.62	5.62	3.10	2.12	1.79	1.84
% CV		53.98	42.73	15.29	23.25	21.18	19.95
			(Planned Comparisons (t Statistics)				
Expt. vs Control (Size 3B)		1.58	2.09*	- .43	-1.06	- .36	- .19

[1]ANOVA performed without shear area covariate therefore residual df equals 72 for sensory evaluation.

and cucumber size. Significant differences were detected in overall texture scores for all main effects and temperature by time interaction. Generally, overall texture of cucumbers decreased significantly with increased holding time at 15°C. Large cucumbers held at 15°C for three days were judged to be the softest.

Poor correlations were obtained between instrumental and sensory evaluations. More detailed discussion of their relationships is presented under the overview of fresh-pack pickle texture.

Further evaluation of green-stock quality was performed using a different cucumber source (Eaton Rapids) to determine effects of refrigerated temperatures on the quality loss.

Cucumbers used were size 3B with average length of 13.4 $\pm$ 0.6 cm and width of 4.7 $\pm$ 0.2 cm.

Mean values for chemical and physical characteristics of green-stock held at 15°C for up to three days prior to brining and statistical analyses of these data are presented in Table 16. Except for soluble solids content, there were no significant differences in chemical composition and textural measures of cucumbers among treatments. A significant linear decrease of soluble solids content was detected with increased holding time.

Evaluation of the texture of cucumber slices from blossom to stem end by Instron center punch showed that the stem end had a significantly firmer texture than the blossom

Table 16. Chemical and physical characteristics and analysis of variance of the characteristics of green-stock cucumbers held at 15°C for up to three days prior to brining.

		Chemical Composition[1]			
		Specific Gravity	pH	Soluble Solids (°B)	Total Acidity (%)
Time (day)		Mean Values and Standard Deviations[2]			
Control		.9722 ± .0115[a]	5.98 ± .08[a]	4.50 ± .00[b]	.067 ± .009[a]
1		.9681 ± .0117[a]	6.07 ± .21[a]	4.38 ± .21[ab]	.068 ± .004[a]
2		.9525 ± .0167[a]	6.10 ± .12[a]	4.38 ± .32[ab]	.061 ± .007[a]
3		.9589 ± .0163[a]	5.98 ± .08[a]	4.02 ± .32[a]	.071 ± .009[a]
Source of Variation	df	Mean Squares			
Time	3	.0001	.0077	.0864*	.0000
Linear	1	.0002	.0001	.2074**	.0000
Deviation	2	.0000	.0114	.0259	.0001
Quadratic	1	.0000	.0220	.0288	.0000
Deviation	1	.0000	.0008	.0230	.0001
Residual	4	.0000	.0110	.0090	.0000
% CV		.00	5.50	2.20	.00
		Planned Comparisons (t Statistics)			
Control vs 1		.69	.86	1.26	- .16
Control vs 2		1.63	-1.14	1.26	1.09
Control vs 3		2.24	.00	5.06**	- .62
1 vs 2		.94	- .29	.00	1.25
1 vs 3		1.55	.86	3.79*	- .47
2 vs 3		.61	1.14	3.79*	-1.72

[1]n = 10 (2 replicates/treatment x 5 cucumbers/replicate).
[2]Like letters within each column indicate no significant differences ($P \geq 0.05$).

Table 16. (cont'd.)

		Textural Measure			
		Slice Punch[3]	Piece Crush[4]		
		Force (kg)	Force (kg)	Work (kg-cm)	Deformation (%)
Time (day)			Mean Values and Standard Deviations		
Control		$.53 \pm .15^a$	8.11 ± 1.48^a	8.01 ± 1.76^a	30.62 ± 4.24^a
1		$.47 \pm .08^a$	7.32 ± 1.17^a	6.90 ± 1.50^a	32.32 ± 4.81^a
2		$.49 \pm .13^a$	6.87 ± 1.63^a	8.14 ± 2.61^a	33.75 ± 7.56^a
3		$.48 \pm .08^a$	6.41 ± 1.05^a	7.12 ± 1.56^a	34.93 ± 7.72^a
Source of Variation	df		Mean Squares		
Time	3	.0016	1.06	.78	6.93
Linear	1	.0022	3.10	.20	20.65
Deviation	2	.0013	.03	1.06	.07
Quadratic	1	.0014	.06	.00	.14
Deviation	1	.0012	.01	2.13	.00
Residual	4	.0040	.46	.93	3.69
% CV		12.86	9.45	12.79	5.83
			Planned Comparisons (t Statistics)		
Control vs 1		.99	1.17	1.15	.89
Control vs 2		.72	1.84	- .13	-1.63
Control vs 3		.87	2.52	.92	-2.25
1 vs 2		-.28	.66	-1.29	- .74
1 vs 3		-.12	1.34	- .23	-1.36
2 vs 3		.16	.68	1.06	- .62

[3] n = 40 (2 replicates/treatment x 5 cucumbers/replicate x 4 slices/cucumber).
[4] n = 20 (2 replicates/treatment x 5 cucumbers/replicate x 2 pieces/cucumber).

end (Figure 5). Results from piece crush tests were similar to those from the refrigerated temperature study.

Data obtained in this study indicated that differences in chemical composition were significant between large (3B) and small (2B) cucumbers. Large cucumbers had lower pH but higher specific gravity, soluble solids, and total acidity than smaller cucumbers. Cucumber (MSU) texture appeared to be firmer at the stem end than at the blossom end and decreased generally with increased holding temperature and time. Holding cucumbers under refrigerated temperatures for two and three days prior to brining did not cause significant deterioration of salt-stock and fresh-pack pickle quality. Cucumbers from Eaton Rapids held at 15°C for up to three days did not exhibit significant loss of green-stock quality.

Fluctuated Temperature Study

Green-Stock Analysis

Mean values for chemical and physical characteristics of green-stock cucumbers held at refrigerated temperatures followed by subsequent exposure to a higher temperature prior to brining and statistical analyses of these data are presented in Table 17. Cucumbers used were size 3B with average length of 13.7 $\pm$ 0.8 cm and width of 4.7 $\pm$ 0.2 cm.

No significant differences were shown in chemical composition and textural measures for any treatment tested in this study.

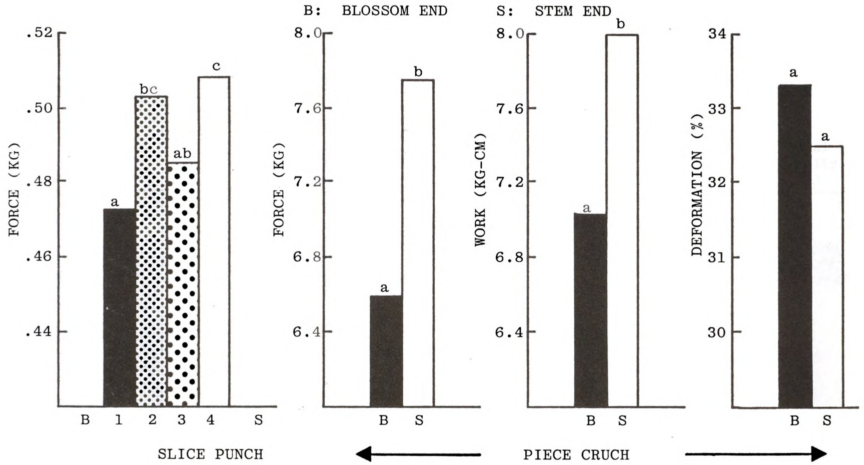

Figure 5. Effect of cucumber slice and piece locations on mean texture measure values (over time) for cucumbers held at 15°C for up to three days prior to brining (like letters within each groun indicate no significant differences, $p \geq 0.05$).

Table 17. Chemical and physical characteristics and analysis of variance of the characteristics of green-stock cucumbers held at 2 and 15°C for one day and transferred to 28°C for an additional day prior to brining.

		Chemical Composition[1]			
		Specific Gravity	pH	Solids (°B)	Total Acidity (%)
Treatment		Mean Values and Standard Deviations[2]			
Control		$.9722 \pm .0115^{a}$	$5.98 \pm .01^{a}$	$4.50 \pm .00^{a}$	$.067 \pm .070^{a}$
2°C - 28°C		$.9640 \pm .0147^{a}$	$6.03 \pm .15^{a}$	$3.96 \pm .56^{a}$	$.087 \pm .023^{a}$
15°C - 28°C		$.9720 \pm .0086^{a}$	$6.12 \pm .10^{a}$	$4.14 \pm .44^{a}$	$.075 \pm .014^{a}$
Source of Variation	df	Mean Squares			
Treatment	2	.0000	.0101	.1512	.0002
Linear	1	.0001	.0025	.2916	.0004
Deviation	1	.0001	.0176*	.0108	.0000
Residual	3	.0000	.0013	.1248	.0002
% CV		.00	.60	8.41	18.53
		Planned Comparisons (t Statistics)			
2 - 28 vs 15 - 28		-2.01	-2.53	- .51	.85
2 - 28 vs Control		-2.06	1.40	-1.53	1.42
15 - 28 vs Control		- .05	3.93*	-1.02	.57

[1]n = 10 (2 replicates/treatment x 5 cucumbers/replicate).
[2]Like letters within each column indicate no significant differences ($P \geq 0.05$).

Table 17. (cont'd.)

		Textural Measure			
		Slice Punch[3]	Piece Crush[4]		
		Force (kg)	Force (kg)	Work (kg-cm)	Deformation (%)
			Mean Values and Standard Deviations		
Treatment					
Control		$.53 \pm .15^a$	8.11 ± 1.48^a	8.01 ± 1.76^a	30.62 ± 4.24^a
2°C - 28°C		$.58 \pm .16^a$	7.85 ± 1.62^a	8.33 ± 1.95^a	29.25 ± 6.57^a
15°C - 28°C		$.47 \pm .13^a$	6.28 ± 1.04^a	6.56 ± 1.52^a	31.08 ± 7.20^a
Source of Variation	df		**Mean Squares**		
Treatment	2	.0070	1.96	1.79	1.80
Linear	1	.0025	.07	.11	1.86
Deviation	1	.0114	3.85	3.47	1.74
Residual	3	.0042	.31	.37	5.06
% CV		12.30	7.52	7.98	7.42
			Planned Comparisons (t Statistics)		
2 - 28 vs 15 - 28		1.81	2.82	2.91	-.81
2 - 28 vs Control		.77	- .47	.53	-.61
15 - 28 vs Control		-1.04	-3.28*	-2.38	.20

[3]n = 40 (2 replicates/treatment x 5 cucumbers/replicate x 4 slices/cucumber).
[4]n = 20 (2 replicates/treatment x 5 cucumbers/replicate x 2 pieces/cucumber).

Results of the effect of location within the cucumber on texture evaluation are shown in Figure 6. Increasing force values from slice 2 through slice 4, though not significantly different from each other, exhibited significantly higher force values than did slice 1 which was closest to the blossom end. Piece crush force and work showed that stem ends were significantly firmer than blossom ends. Percent deformation of both ends, though not significantly different from each other, showed a decrease from blossom end to stem end.

Salt-Stock Analysis

Visual Evaluation. Mean values for visual defect classification of salt-stock cucumbers and statistical analyses of these data are presented in Table 18. No significant differences were shown for any defect class among treatments.

Textural Evaluation. Mean values for salt-stock texture evaluated by the FPT and Instron and statistical analyses of these data are presented in Table 19. Neither FPT nor Instron force values were significantly different among treatments. Significant correlation was observed between FPT and Instron force values ($r = 0.74^*$).

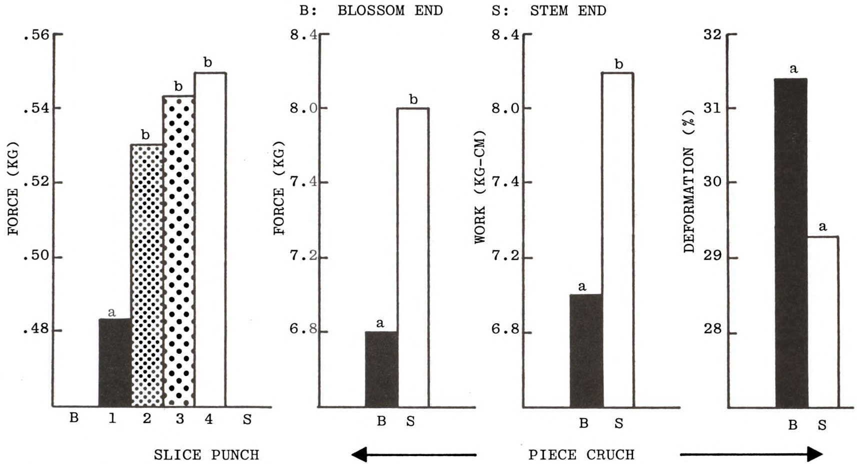

Figure 6. Effects of cucumber slice and piece locations on mean texture measure values (over treatment) for cucumbers held at 2 and 15°C for one day and transferred to 28°C for an additional day prior to brining (like letters within each group indicate no significant differences, $p \geq 0.05$).

Table 18. Visual defect classification and analysis of variance of visual defect classification of salt-stock cucumbers held at 2 and 15°C for one day and transferred to 28°C for an additional day prior to brining.

		Defect Class (%)					Total Soft Among All Defect Classes (%)
		No Damage	Honey-comb	Lens	Balloon	Soft Center	
Treatment		Mean Values and Standard Deviations[1]					
Control		75.0 ± 11.3[a]	16.5 ± 4.9[a]	8.5 ± 2.1[a]	0.0 ± .0[a]	0.0 ± .0[2]	0.0 ± .0
2°C - 28°C		68.5 ± 40.3[a]	13.5 ± 19.1[a]	13.5 ± 19.1[a]	5.0 ± 2.8[a]	0.0 ± .0	0.0 ± .0
15°C - 28°C		60.0 ± .0[a]	28.0 ± 7.1[a]	8.0 ± 7.1[a]	3.0 ± .0[a]	0.0 ± .0	0.0 ± .0
Source of Variation	df	Mean Squares					
Treatment	2	113.17	117.17	18.50	12.67	.00	.00
Linear	1	42.15	9.00	25.00	25.00	.00	.00
Deviation	1	184.08	225.33	12.00	.33	.00	.00
Residual	3	584.17	146.33	139.67	2.67	.00	.00
% CV		35.63	62.57	118.18	61.24	.00	.00
		Planned Comparisons (t Statistics)					
2 - 28 vs 15 - 28		.35	-1.20	.47	1.22	---[3]	---
2 - 28 vs Control		- .27	- .25	.42	3.06	---	---
15 - 28 vs Control		- .62	.95	- .04	1.84	---	---

[1]Like letters within each column indicate no significant differences ($P \geq 0.05$), n = 2 (2 replicates/treatment).
[2]Tukey mean separations are not presented due to no within variance.
[3]t Statistics are not computed due to no within variance.

Table 19. Texture and analysis of variance of texture of salt-stock cucumbers held at 2 and 15°C for one day and transferred to 28°C for an additional day prior to brining.

		Center Puncture Force	
		FPT (lb)	Instron (kg)
Treatment		Mean Values and Standard Deviations[1]	
Control		24.18 ± 3.06[a]	10.49 ± 1.92[a]
2°C - 28°C		22.02 ± 3.35[a]	9.85 ± 1.69[a]
15°C - 28°C		24.43 ± 2.95[a]	10.09 ± 1.34[a]
Source of Variation	df	Mean Squares	
Treatment	2	3.48	.20
Linear	1	4.62	.38
Deviation	1	2.34	.01
Residual	3	1.05	.23
% CV		4.35	4.76
		Planned Comparisons (t Statistics)	
2 - 28 vs 15 - 28		-2.34	- .44
2 - 28 vs Control		-2.10	-1.28
15 - 28 vs Control		.24	- .84

[1]Like letters within each column indicate no significant differences ($P \geq 0.05$), n = 20 (2 replicates/treatment x 10 pickles/replicate).

Fresh-Pack Pickle Analysis

Mean values for instrumental and sensory evaluations of texture of pickle spears and statistical analyses of these data are presented in Table 20.

A linear response in the second peak force was shown for treatment. Flesh texture scores of control were significantly lower than that of 15°C-28°C treatment.

No significant differences were shown in the first and third peak forces and skin and overall texture scores among treatments.

Instron force values were poorly correlated to sensory texture scores.

Results of this study indicated that cucumbers did not exhibit adverse quality changes when exposed to high temperatures for only one day following short time (one day) refrigerated temperature holding.

Relative Humidity Study

Green-Stock Analysis

Mean values and Tukey mean separations for chemical and physical characteristics of green-stock cucumbers obtained from two sources held at different temperatures under various RH's are presented in Table 21. Statistical analyses of these data are outlined in Table 22. Cucumbers from MSU were size 3B with average length of 11.9 ± 0.7 cm and width

Table 20. Instrumental and sensory evaluations of texture and analysis of variance of texture of fresh-pack pickle spears held at 2 and 15°C for one day and transferred to 28°C for an additional day prior to brining.

		Instrumental Evaluation[1]			Sensory Evaluation[2,3]		
		Peak Force (kg) 1st	2nd	3rd	Flesh	Skin	Overall
Treatment		Mean Values and Standard Deviations[4]					
Control		$1.34 \pm .40^{a}$	10.68 ± 1.96^{b}	15.47 ± 1.74^{a}	$5.80 \pm .98^{a}$	$6.80 \pm .92^{a}$	$7.10 \pm .97^{a}$
2°C - 28°C		$1.12 \pm .35^{a}$	8.69 ± 1.52^{ab}	14.68 ± 2.32^{a}	6.20 ± 1.80^{ab}	6.95 ± 1.07^{a}	$7.55 \pm .93^{a}$
15°C - 28°C		$1.18 \pm .27^{a}$	8.61 ± 2.06^{a}	13.99 ± 2.19^{a}	7.40 ± 1.08^{b}	7.50 ± 1.03^{a}	7.70 ± 1.03^{a}
Source of Variation	**df**	Mean Squares					
Treatment	2	.12	13.79*	5.48	6.93*	1.36	.98
Linear	1	.24	19.80*	3.10	.80	.11	1.01
Deviation	1	.02	7.78	7.86	13.07*	2.60	.94
Residual	27	.12	3.47	4.40	1.78	1.01	.95
% CV		28.42	19.97	14.26	20.64	14.20	13.10
		Planned Comparisons (t Statistics)					
2 - 28 vs 15 - 28		- .35	.10	.74	-2.01	-1.22	- .34
2 - 28 vs Control		-1.38	-2.39*	- .84	.67	.33	1.03
15 - 28 vs Control		-1.03	-2.49*	-1.58	-2.68*	1.56	1.37

[1] n = 20 (2 replicates/treatment x 5 pickles/replicate x 2 shears/pickle).
[2] n = 20 (2 replicates/treatment x 5 panelists/replicate x 2 tests/panelist).
[3] Nine = extremely firm/crisp.
[4] Like letters within each column indicate no significant differences ($P \geq 0.05$).

Table 21. Chemical and physical characteristics of green-stock cucumbers from MSU and Eaton Rapids held at 2 and 28°C under selected relative humidities for two days prior to brining.[1]

Treatment Temp, RH (°C, %)		Specific Gravity	pH	Soluble Solids (°B)	Total Acidity (%)
		Chemical Composition[2]			
			MSU		
Control		.9554 ± .0076^{abcd}	6.05 ± .07^{abc}	3.90 ± .00de	.069 ± .007^{b}
2	0	.9545 ± .0173^{abcd}	6.14 ± .11^{abc}	3.27 ± .22^{abcd}	.051 ± .008^{a}
	75	.9609 ± .0159^{abcd}	6.20 ± .09^{abcd}	3.09 ± .14^{abc}	.055 ± .010^{ab}
	100	.9557 ± .0124^{abcd}	6.23 ± .08^{abcd}	2.97 ± .17^{abc}	.058 ± .007^{ab}
28	0	.9444 ± .0238^{abc}	6.33 ± .28^{cd}	3.03 ± .09^{abc}	.058 ± .012^{ab}
	75	.9381 ± .0173^{a}	6.69 ± .29^{e}	2.67 ± .22^{a}	.044 ± .010^{a}
	100	.9418 ± .0138^{ab}	6.48 ± .30de	2.82 ± .15^{ab}	.051 ± .011^{a}
			Eaton Rapids		
Control		.9722 ± .0115^{d}	5.98 ± .08^{a}	4.50 ± .00^{e}	.067 ± .009^{b}
2	0	.9645 ± .0119^{bcd}	6.02 ± .06^{abc}	3.48 ± .25^{bcd}	.055 ± .012^{ab}
	75	.9692 ± .0125^{cd}	6.12 ± .09^{abc}	3.57 ± .30^{cd}	.057 ± .007^{ab}
	100	.9630 ± .0104^{abcd}	5.99 ± .11^{ab}	3.27 ± .30^{abcd}	.059 ± .006^{ab}
28	0	.9385 ± .0291^{a}	6.27 ± .11^{abcd}	3.87 ± 1.08^{de}	.055 ± .006^{ab}
	75	.9514 ± .0107^{abcd}	6.20 ± .11^{abcd}	3.33 ± .17^{abcd}	.050 ± .004^{a}
	100	.9503 ± .0150^{abcd}	6.30 ± .10^{bcd}	3.30 ± .24^{abcd}	.051 ± .009^{a}

[1]Mean values and standard deviations (like letters within each column indicate no significant differences, $P \geq 0.05$).
[2]n = 10 (2 replicates/treatment x 5 cucumbers/replicate).

Table 21. (cont'd.)

Treatment Temp, RH (°C, %)		Textural Measure: Slice Punch[3] Force (kg)	Piece Crush[4] Force (kg)	Piece Crush[4] Work (kg-cm)	Piece Crush[4] Deformation (%)	Weight[5] Loss (%)
				MSU		
Control		$.46 \pm .05^{a}$	$4.95 \pm .57^{ab}$	4.46 ± 1.00^{ab}	31.29 ± 5.88^{a}	---
2	0	$.51 \pm .06^{a}$	$4.94 \pm .38^{ab}$	4.76 ± 1.35^{abc}	32.26 ± 6.79^{a}	$2.03 \pm .11^{c}$
	75	$.50 \pm .10^{a}$	$5.31 \pm .76^{abc}$	4.17 ± 1.38^{a}	33.98 ± 7.03^{a}	$1.93 \pm .05^{c}$
	100	$.47 \pm .08^{a}$	$4.91 \pm .69^{ab}$	4.66 ± 0.91^{ab}	31.21 ± 6.09^{a}	$1.01 \pm .06^{b}$
28	0	$.54 \pm .24^{a}$	4.46 ± 1.70^{a}	4.06 ± 2.24^{a}	33.24 ± 7.28^{a}	$2.82 \pm .30^{d}$
	75	$.49 \pm .10^{a}$	4.93 ± 1.54^{ab}	4.79 ± 1.60^{abc}	36.23 ± 6.51^{a}	$1.92 \pm .16^{c}$
	100	$.57 \pm .14^{a}$	5.14 ± 1.15^{ab}	5.14 ± 1.39^{abcd}	33.55 ± 5.09^{a}	$.26 \pm .03^{a}$
				Eaton Rapids		
Control		$.53 \pm .15^{a}$	8.11 ± 1.48^{d}	8.01 ± 1.76^{f}	30.62 ± 4.24^{a}	---
2	0	$.49 \pm .09^{a}$	$6.39 \pm .94^{bcd}$	6.64 ± 1.26^{cdef}	34.86 ± 6.80^{a}	$1.86 \pm .09^{c}$
	75	$.44 \pm .07^{a}$	6.99 ± 1.21^{cd}	7.50 ± 1.54^{ef}	33.21 ± 6.67^{a}	$1.86 \pm .15^{c}$
	100	$.44 \pm .10^{a}$	6.44 ± 1.59^{cd}	6.96 ± 1.24^{def}	31.16 ± 6.26^{a}	$1.08 \pm .01^{b}$
28	0	$.40 \pm .09^{a}$	6.03 ± 1.38^{abc}	6.36 ± 1.71^{bcdef}	35.21 ± 3.82^{a}	$1.91 \pm .19^{c}$
	75	$.40 \pm .10^{a}$	6.43 ± 1.37^{cd}	5.76 ± 1.05^{abcde}	35.82 ± 5.43^{a}	$2.02 \pm .20^{c}$
	100	$.47 \pm .10^{a}$	6.95 ± 1.40^{cd}	6.67 ± 1.63^{cdef}	31.36 ± 4.96^{a}	$.22 \pm .20^{a}$

[3] n = 40 (2 replicates/treatment x 5 cucumbers/replicate x 4 slices/cucumber).
[4] n = 20 (2 replicates/treatment x 5 cucumbers/replicate x 4 slices/cucumber).
[5] n = 2 (2 replicates/treatment).

Table 22. Analysis of variance of chemical and physical characteristics of green-stock cucumbers from MSU and Eaton Rapids held at 2 and 28°C under selected relative humidities for two days prior to brining.

Source of Variation	df	Specific Gravity	pH	Soluble Solids (°B)	Total Acidity (%)
		Chemical Composition			
		Mean Squares			
Main Effects	4	0.001***	0.172***	0.498***	0.000
Cucumber Source (CS)	1	0.000*	0.228***	0.470***	0.000
Temperature (Tp)	1	0.002*	0.411***	1.066	0.000*
RH	2	0.000	0.025	0.228*	0.000
Two-way	5	0.000	0.012	0.074	0.000
CS x Tp	1	0.000	0.014	0.163	0.000
CS x RH	2	0.000	0.019	0.018	0.000
Tp x RH	2	0.000	0.003	0.085	0.000*
Three-way					
CS x Tp x RH	2	0.000	0.037*	0.034	0.000
Residual	12	0.000	0.007	0.039	0.000
% CV		0.00	1.34	6.13	0.00
		Planned Comparisons (t Statistics)			
0% RH vs 75% RH		-1.27	-2.85*	2.70*	1.65
0% RH vs 100% RH		- .61	-1.52	3.52**	.00
75% RH vs 100% RH		.67	1.33	.82	-1.65
Expt. vs Control (MSU)		-1.23	4.89***	-6.61***	-5.36***
Expt. vs Control (E.R.)		-3.16**	2.82*	-7.36***	-4.15***

Table 22. (cont'd.)

Source of Variation	df	Textural Measure: Slice Punch Force (kg)	Piece Crush: Force (kg)	Piece Crush: Work (kg-cm)	Piece Crush: Deformation (%)	Weight Loss (%)
				Mean Squares		
Main Effects	4	.009	4.08***	6.64***	12.61	2.72***
Cucumber Source (CS)	1	.034*	15.12***	25.27***	.22	.18*
Temperature (Tp)	1	.000	.18	.60	12.67	.06
RH	2	.002	.51	.35	18.77*	5.31***
Two-way	5	.004	.18	.36	3.53	.42***
CS x Tp	1	.006	.01	1.22*	.98	.08
CS x RH	2	.000	.01	.03	6.71	.20**
Tp x RH	2	.006	.44	.26	1.62	.80***
Three-way						
CS x Tp x RH	2	.001	.03	.97	.79	.11*
Residual	12	.005	.19	.26	4.65	.02
% CV		15.04	7.57	9.04	6.43	9.66
		Planned Comparisons (t Statistics)				
0% RH vs 75% RH		.68*	-2.04***	- .43***	- .87	3.11**
0% RH vs 100% RH		- .12	-1.81	-1.65	1.97	21.35***
75% RH vs 100% RH		- .80	.23	-1.22	2.84*	18.23***
Expt. vs Control (MSU)		1.05	.00	.35	1.32	15.37***
Expt. vs Control (E.R.)		-1.79	-4.58***	-3.63**	1.86	13.79***

of 4.4 $\pm$ 0.3 cm. Cucumbers from Eaton Rapids were size 3B with average length of 13.0 $\pm$ 0.9 cm and width of 4.6 $\pm$ 0.2 cm.

Chemical Composition. Main effects for cucumber source and holding temperature were significant for specific gravity and pH values of cucumbers. Cucumbers from MSU had significantly lower specific gravity but higher pH values than those from Eaton Rapids. Increase in temperature caused a significant decrease in specific gravity and a significant increase in pH values for cucumbers from both sources. A significant difference in specific gravity was shown between control and any of the treatments for cucumbers from Eaton Rapids. pH values of the control were shown to be significantly lower than those of other treatments, regardless of the source.

Significant differences in soluble solids content were detected for cucumber source and RH. Soluble solids values of cucumbers from Eaton Rapids were significantly higher than those from MSU. Cucumbers held in 75 and 100% RH's, though not significantly different from each other, exhibited significantly lower Brix values when compared to cucumbers held in 0% RH.

Significant main effect differences in total acidity were detected for holding temperature and the interaction with RH. Generally, for each level of RH percent total acidity decreased significantly with increased holding temperature. Cucumbers measured immediately after harvest had significantly higher percent total acidity than those held at 28°C under 75 and 100% RH's.

Textural Measure. No significant differences were detected in slice punch forces among treatments.

Significant main effect differences in piece crush forces and work were detected for cucumber source. Cucumber source by temperature interaction was also detected to be significant in piece crush work. Cucumbers from Eaton Rapids had significantly higher piece crush force and work when compared to those from MSU. Percent deformation showed no significant differences among treatments.

Effect of location within the cucumber on textural evaluations of Instron punch and crush is shown in Figure 7. Slice punch force increased from blossom end to stem end. Slice 2 and 3, though notsignificant different from each other, were significantly higher than slice 1 but lower than slice 4. Significant increases of piece crush forces as well as piece crush work were shown from blossom end to stem end. Percent deformation decreased significantly from blossom to stem end indicating a firmer texture at the stem end.

In this study slice punch forces were not correlated well to any of the piece crush measures of cucumbers. Piece crush forces were significantly correlated to piece crush work (r = 0.90***).

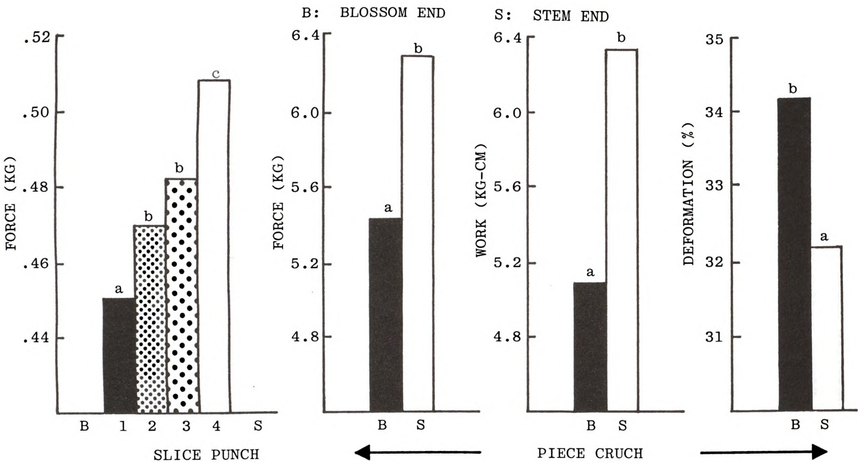

Figure 7. Effect of cucumber slide and piece locations on mean textural measure values (over variety, temperature, and relative humidity) for cucumbers from MSU and Eaton Rapids held at 2 and 28°C under selected relative humidities for two days prior to brining (like letters within each group indicate no significant differences, $p \geq 0.05$).

Weight Loss. Significant differences in main effects were detected for cucumber source and RH. Cucumber source by RH and temperature by RH interactions were also shown to be significant. Generally, weight loss of cucumbers during holding decreased significantly with increased level of RH during two days holding period. Etchells et al. (1973a) reported that moisture loss of the cucumbers was rapid with combinations of high temperature and low humidities during six-day storage. The results of the present study suggest that high temperature holding for only two days may not cause severe moisture loss under high relative humidities.

Fresh-Pack Pickle Analysis

Mean values and Tukey mean separations for instrumental and sensory evaluations of fresh-pack pickles held at different temperatures under various RH's are presented in Table 23. Statistical analyses of these data are summarized in Table 24.

The first peak forces were not affected by cucumber cross sectional area or the experimental RH conditions. High temperature holding resulted in significantly decreased first peak force values.

Analysis of covariance showed that shear area of spears had significant effects on both the second and third peak forces. Cucumber source and temperature were shown to have significant main effect differences on the second and third peak forces. Generally, cucumbers from Eaton Rapids

Table 23. Instrumental and sensory evaluations of texture of fresh-pack pickle spears from MSU and Eaton Rapids held at 2 and 28°C under selected relative humidities for two days prior to brining.[1]

Temp, RH (°C, %)		Instrumental Evaluation[2] Peak Force (kg) 1st	2nd	3rd	Sensory Evaluation[3,4] Flesh	Skin	Overall
				MSU			
Control		.97 ± .41^{ab}	4.75 ± 2.63^{a}	13.50 ± 3.42^{ab}	5.90 ± .91^{a}	6.00 ± .82^{a}	6.40 ± .97^{a}
	0	1.03 ± .40^{ab}	6.74 ± 2.69^{abc}	12.79 ± 1.51^{ab}	5.60 ± 1.10^{a}	6.60 ± .77^{a}	7.10 ± .88^{a}
2	75	1.21 ± .23^{ab}	5.82 ± 3.04^{ab}	13.67 ± 1.32^{ab}	5.75 ± 1.74^{a}	6.50 ± 1.22^{a}	7.05 ± .96^{a}
	100	1.07 ± .23^{ab}	8.22 ± 2.01^{abcd}	13.20 ± 1.16^{ab}	5.40 ± 1.05^{a}	6.10 ± 1.02^{a}	6.85 ± .91^{a}
	0	1.20 ± .32^{ab}	7.47 ± 3.92^{abcd}	12.00 ± 3.21^{a}	5.10 ± 1.10^{a}	6.25 ± .83^{a}	6.70 ± 1.25^{a}
28	75	.88 ± .18^{a}	6.68 ± 2.04^{abc}	12.03 ± 2.12^{a}	4.85 ± 1.16^{a}	5.85 ± 1.11^{a}	6.00 ± 1.29^{a}
	100	1.01 ± .29^{ab}	7.12 ± 2.15^{abc}	13.20 ± 2.61^{ab}	5.62 ± 1.10^{a}	6.25 ± 1.01^{a}	6.40 ± 1.17^{a}
				Eaton Rapids			
Control		1.34 ± .40^{ab}	10.68 ± 1.96^{d}	15.48 ± 1.72^{b}	5.80 ± .98^{a}	6.80 ± .92^{a}	7.10 ± .97^{a}
	0	1.27 ± .21^{ab}	8.60 ± 2.07^{bcd}	13.36 ± 1.84^{ab}	6.50 ± 1.41^{a}	6.90 ± 1.39^{a}	7.10 ± 1.37^{a}
2	75	1.23 ± .19^{ab}	9.59 ± 2.18^{cd}	15.58 ± 1.66^{b}	6.00 ± 1.00^{a}	6.65 ± .71^{a}	7.20 ± .59^{a}
	100	1.39 ± .63^{b}	8.91 ± 2.32^{bcd}	14.53 ± 2.38^{ab}	5.60 ± 1.47^{a}	6.45 ± .96^{a}	7.10 ± .91^{a}
	0	1.25 ± .32^{ab}	8.09 ± 1.28^{abcd}	13.66 ± 2.27^{ab}	5.70 ± 1.48^{a}	6.85 ± 1.23^{a}	7.05 ± 1.12^{a}
28	75	1.14 ± .26^{ab}	8.75 ± 1.67^{bcd}	13.35 ± 2.25^{ab}	6.05 ± 1.64^{a}	6.65 ± 1.42^{a}	7.30 ± 1.20^{a}
	100	.93 ± .21^{ab}	7.59 ± 1.21^{abcd}	12.45 ± 1.69^{ab}	6.30 ± 1.42^{a}	6.75 ± 1.01^{a}	7.00 ± 1.15^{a}

[1]Mean values and standard deviation (like letters within each column indicate no significant differences, $P > 0.05$).
[2]$n = 20$ (2 replicates/treatment x 5 pickles/replicate x 2 shears/pickle).
[3]$n = 20$ (2 replicates/treatment x 5 panelists/replicate x 2 tests/panelist).
[4]Nine = extremely firm/crisp.

Table 24. Analysis of variance of instrumental and sensory evaluations of texture of fresh-pack pickle spears from MSU and Eaton Rapids held at 2 and 28°C under selected relative humidities for two days prior to brining.

		Instrumental Evaluation			Sensory Evaluation		
			Peak Force (kg)				
Source of Variation	df	1st	2nd	3rd	Flesh	Skin	Overall
				Mean Squares			
Covariate							
Shear Area	1	.02	114.69***	118.06***	---[1]	---	---
Mean Effects	4	.30*	7.37	14.59**	2.22	2.01	2.37
Cucumber Source (CS)	1	.47*	19.37*	.50	6.67	6.18*	5.85*
Temperature (Tp)	1	.51*	7.75	47.26***	.04	.30	3.17
RH	2	.07	.31	5.12	1.18	.84	.23
Two-way	5	.15	7.56	4.24	1.05	.54	.94
CS x Tp	1	.11	9.17	2.72	.01	1.01	2.85
CS x RH	2	.00	10.00	1.17	.57	.01	.76
Tp x RH	2	.33*	4.35	8.03	2.05	.63	.18
Three-way							
CS x Tp x RH	2	.28	7.81	2.00	3.52	.17	.53
Residual	107	.10	4.85	3.56	1.76	1.16	1.20
% CV		27.70	28.23	14.16	22.91	16.63	15.90
			Planned Comparisons (t Statistics)				
0% RH vs 75% RH		.93	.02	-1.44	1.09	1.01	.41
0% RH vs 100% RH		1.13	- .45	- .80	.86	1.12	.62
75% RH vs 100% RH		.28	- .48	.64	- .24	.11	.21
Expt. vs Control (MSU)		.88	2.85**	- .92	- .79	.72	.77
Expt. vs Control (E.R.)		-1.19	-2.64**	-2.22*	.52	- .26	.07

[1]ANOVA performed without shear area covariate therefore residual df equals 108 for sensory evaluation.

had significantly higher second peak forces than did MSU cucumbers. The third peak forces decreased significantly with increased holding temperature.

No significant main effect differences were detected for any sensory texture evaluation among treatments.

Poor correlation was observed between Instron force values and sensory scores.

In summary, levels of RH used in this study seemed to have little effect on chemical composition of cucumbers during two-day holding. Cucumbers held at higher temperatures under high RH's for two days may not show significant moisture loss. Cucumber texture did not change significantly under different treatments prior to processing. High temperature holding seemed to reduce the skin firmness of fresh-pack pickle spears.

Overview of Fresh-Pack Pickle Texture

In order to further investigate the nature of fresh-pack pickle spear texture instrumental and sensory evaluation data were pooled from all the experiments, thus establishing 260 determinations suitable for statistical analyses.

Each of the force curves obtained from the Instron measurement was characterized into the first, second, and third peak forces which were assumed to result from the forces required to shear through the seed-flesh, flesh and skin edges, and skin of pickle spears, respectively.

The first peak forces were detected to be poorly correlated with the second and third peak forces. This was probably due primarily to the extreme variability among the first peak forces resulting from the rather complicated seed-flesh portion and poorly defined fracture peaks. In addition, the uneven lengthwise slicing of cucumbers could have contributed to various flesh to seed cavity proportions which were very critical in measuring the first peak forces. Further, there is no physiological reason to suspect that there would be a relationship between seed cavity and the outer flesh. Spears with greater proportions of seed cavity tissue may have lower first peak forces than those with smaller seed cavity proportions although the former spears were higher in second and third peak forces than the latter ones.

Correlation of the second peak force with the third peak force was significant (r = 0.52***); however, this relationship may provide limited meaning since high variability was also shown among the second peak forces and many of the pickle spears did not even exhibit the second peak during crosscut shearing.

A significant correlation was shown between numbers of the second peak and shapes of pickle spears indicating that the more curved skin resulted in the increased frequency of the second peaks. Absence of the second peaks, therefore, is probably due to the flat skin (shape 1) of spears.

Sensory scores of flesh, skin, and overall texture from all treatments of the studies were compared (Figures 8 through 10). Regression equations and correlation coefficients are given in each figure. High correlations were found between sensory texture scores. Overall texture scores were highly significantly correlated to skin texture scores indicating that the overall texture quality, as determined by sensory evaluation, is strongly associated with the skin texture.

Correlation coefficients were computed to relate peak force values to sensory texture scores. Results indicated that poor correlations were shown between the first peak forces and flesh texture scores; the third peak forces and skin texture scores; the average of three peak forces and overall texture scores. It was suspected that shear areas of spears may have dramatic effect on the peak force values and, thus, cause deviations of the results. Improper intensity of the sensory scale may have been responsible for poor texture discrimination which caused the discrepancy in correlations between sensory and instrumental data.

To evaluate the effect of shear area on peak force values, correlation coefficients relating shear areas to each of the three peak forces were computed. Poor correlation was shown between the first peak forces and shear areas indicating that the first peak forces were independent of shear areas. However, significant correlations were observed between the second peak forces and shear areas, as

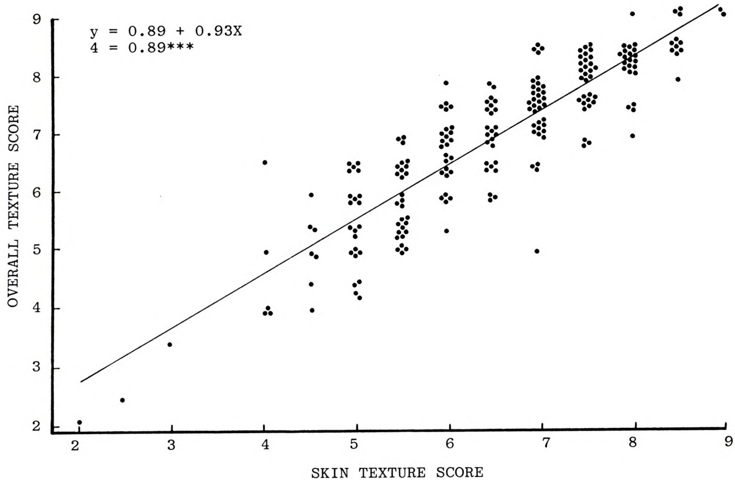

Figure 8. Scatter diagram, regression equation, and correlation coefficient for overall texture scores vs. skin texture scores of sensory evaluation of fresh-pack pickle spears from all treatments of the studies.

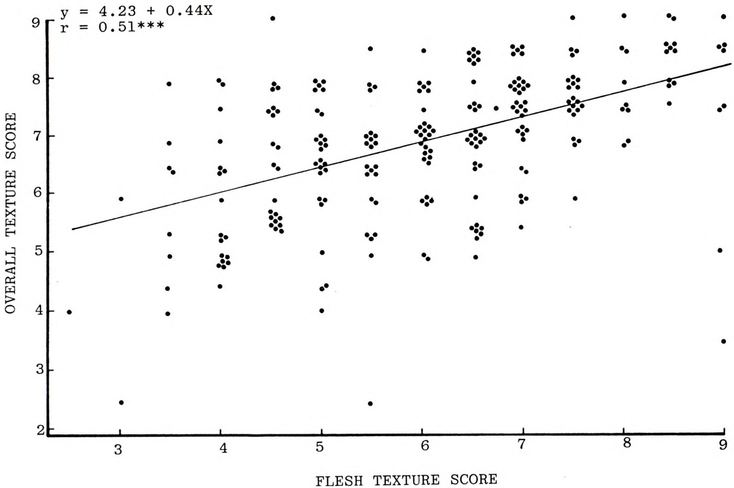

Figure 9. Scatter diagram, regression equation, and correlation coefficient for overall texture scores vs. flesh texture scores of sensory evaluation of fresh-pack pickle spears from all treatments of the studies.

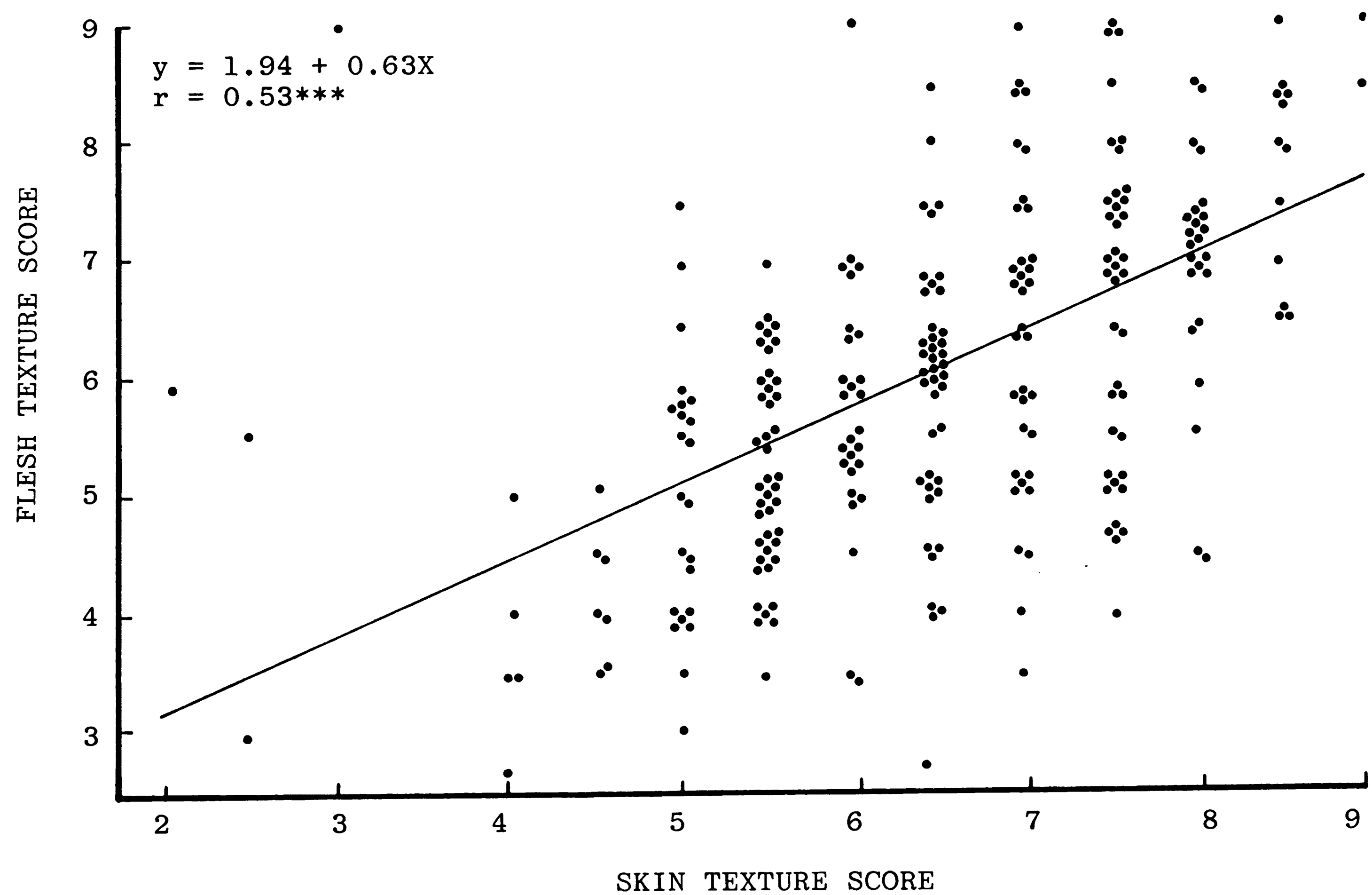

Figure 10. Scatter diagram, regression equation, and correlation coefficient for flesh texture scores vs. skin texture scores of sensory evaluation of fresh-pack pickle spears from all treatments of the studies.

well as between the third peak forces and shear areas. Based on the above findings, investigation was made to correlate shear resistances (peak force/shear area) with the corresponding sensory texture scores. Correlation coefficients obtained from each of the comparisons, however, were also too low to provide a meaningful relationship between instrumental and sensory measures.

It may be concluded that the complex nature of seed-flesh tissue and the variation in sample dimension may have contributed to the poor correlation between the first peak forces and sensory flesh texture scores. The third peak forces, though not correlated well with sensory skin scores, tended to be better indications of spear texture. Poor correlations between the third peak forces and skin texture scores may be attributed mainly to the constrictive sensory evaluation scale. The lack of correlation between the average of three peak forces and overall texture scores may have resulted from the high variability of the first and second peak forces. These results did not support the hypothesis that the instrumental analysis technique developed in this study bears relationship to sensory evaluation of texture of fresh-pack pickle spears. Further research is needed to develop better techniques in defining the peak curves in relationship to the texture of seed cavity, flesh, and skin. It should also be emphasized that researchers be judicious in selecting spears of uniform size and shape to avoid variability arising from differences in the proportions of flesh to seed cavity tissue. The number of determinations may be increased to reduce sampling variations. The contradictory data on correlations between instrumental and sensory measures may have been caused by a too constrictive sensory scale employed in the studies. Development of a proper intensity scale may improve the sensory judges' discrimination of the texture property among samples.

Instrumental methods were sufficient to distinguish textural differences among experimental conditions and suitable for experimental evaluation of cucumber product firmness; however, correlations to sensory texture scores were not established.

SUMMARY AND CONCLUSION

Results of the factorial postharvest study indicated that the chemical and physical changes of green-stock cucumbers were generally a function of postharvest holding conditions. Cucumbers held at 5°C for up to six days showed firm texture, low respiration rates, minimum weight loss, and good quality stock after fermentation. Increasing postharvest holding temperatures and times prior to brining resulted in loss of firmness, high respiration rates, increased weight loss, and a decrease in salt-stock quality. Cucumber texture was generally firmer at the stem end than at the blossom end. Salt-stock pickle defects increased dramatically under high temperature/long time holding periods. Postharvest holding of cucumbers before brining is very detrimental to final salt-stock pickle quality. Quality loss is accelerated at temperatures ranging from 20 to 30°C due primarily to textural degradation and internal enzymatic softening.

In the refrigerated temperature study, cucumber size was shown to influence chemical composition of green-stock. The texture of cucumbers from MSU appeared to be firmer at the stem end than at the blossom end and decreased generally with increased holding temperature and time. Holding cucumbers

under refrigerated temperatures for two and three days prior to brining did not have significant effect on salt-stock and fresh-pack pickle quality. Cucumbers from Eaton Rapids held at 15°C for up to three days did not exhibit significant loss of green-stock quality.

Holding cucumbers under refrigerated temperatures for one day followed by subsequent exposure to a higher temperature for an additional day did not cause reduction in cucumber product quality.

Data indicated that relative humidity appeared to have little effect on the chemical composition of cucumbers held two days at 2 and 28°C. Moisture loss was high under 0% and 75% RH; however, no significant moisture loss was shown under 100% RH. Differences in cucumber texture were not significant among treatments. Cucumbers held at high temperature resulted in reduction of pickle skin texture.

Slice punching and piece crushing tests using the Instron indicated that slices and pieces near the stem end tend to be firmer than those located at the blossom end. This result is in agreement with that obtained by Breene _et al_. (1972) who explained that there is an increased skin thickness toward the stem end and a greater proportion of flesh relative to seed cavity tissue.

Piece crushing expressed in force, work, and deformation showed that a similar relationship occurs in cucumbers. That is, a firm cucumber will likely exhibit a lower value for piece crush deformation and higher values for piece crush force and work than will a soft cucumber. The trend of these expressions to parallel each other suggests that textural quality may be assessed by measuring one or all of them.

Significant correlations were shown between textural evaluations by the FPT and Instron puncture tests for salt stock.

Sensory evaluation of cucumber texture from all treatments of the studies showed that overall texture of pickle spears was strongly associated with skin texture. Poor correlations were detected between instrumental and sensory measures. Further research is needed to establish relationships between objective and subjective evaluations of cucumber product texture.

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