EFFECTS OF STORAGE CONDITIONS ON FIRMNESS OF BRINED CUCUMBERS

R. L. THOMPSON, H. P. FLEMING and R. J. MONROE

ABSTRACT

Brined, fermented cucumbers were stored up to 1 yr under various conditions of pH (3.3, 3.8), NaCl concentration (5.5, 11.4%), temperature (4.4, 15.5, 26.6°C), storage time (3, 6, 9, 12 months), and $CaCl_2$ addition (0.1%). Polygalacturonase (PG) activity in the brine was negligible. Firmness of the cucumbers was determined with a Magness-Taylor fruit pressure tester. Temperature had the greatest influence upon retention of firmness, but effects of pH, % NaCl, and storage time also were significant ($P \leq 0.01$). Rates of firmness loss ranged from <0.05 to ca 0.5 lb/month, depending upon pH, % NaCl and temperature. Firmness retention was greatest at 4.4–15.5°C, pH 3.8 and 11.4% NaCl. A prediction equation for the rate of firmness loss was developed. Addition of 0.1% $CaCl_2$ to the brine resulted in firmer cucumbers, particularly those stored at pH 3.3 ($P < 0.01$). Results indicated that firmness of cucumbers can be retained at lower brine strengths than currently used, provided the cucumbers are washed prior to brining to remove softening enzymes as in the controlled fermentation process, and temperature of the brine stock is maintained at ca 15.5°C or lower.

INTRODUCTION

FIRMNESS and crispness are primary traits affecting consumer acceptance of pickled cucumbers. Variations in firmness among cucumber cultivars may account for differences in quality of the pickled product (Jones et al., 1954; Breene et al., 1973; Sneed and Bowers, 1970). Processing methods undoubtedly play a major role in firmness. The firmness of fresh pack cucumbers is affected by variables such as pasteurization time and temperature, pH and acidity, and storage time and temperature (Monroe et al., 1969, Fellers and Pflug, 1965; Pangborn et al., 1959).

Firmness of brined cucumbers depends on the vagaries of microbial activities as well as the storage conditions of the cucumbers. Microbial polygalacturonases, whether introduced into the brining tank by attachment to the fruit or flower as shown by Etchells et al. (1958) or produced in the brining tank, can greatly reduce the firmness of the brined cucumbers. The initial load of such enzymes–particularly on small fruits, which retain a greater percentage of polygalacturonase-laden flowers–could be effectively reduced if the brining tank is drained after ca 36 hr (Etchells et al., 1955). Microbial polygalacturonases, active in softening brined cucumbers, are inhibited by high levels of NaCl (Bell and Etchells, 1961); and briners have used high levels of salt to retard enzymatic softening. Increasing difficulties with salt disposal have caused briners to seek means of reducing the level of salt used.

The controlled fermentation process of Etchells et al. (1973) provides a possible means of storing brined cucumbers at low levels of salt. The process includes a washing step to remove soil, enzymes and unwanted microorganisms. Thus, softening of cucumbers by microbial polygalacturonases should be low. Under these conditions the major factors affecting the firmness of brined cucumbers would include temperature, pH, salt concentration, and storage time.

The purpose of this study was to determine the relative importance of the above factors on the firmness of cucumbers fermented by the controlled fermentation process. Also, effects of calcium chloride addition to the storage brine on firmness were evaluated.

Authors Thompson and Fleming are with the USDA Food Fermentation Lab., SEA-AR, and Dept. of Food Science, North Carolina State University, Raleigh, NC 27650. Author Monroe is with the Dept. of Statistics, North Carolina State University, Raleigh, NC 27650.

MATERIALS & METHODS

THE CUCUMBERS used in these studies were brined according to the controlled fermentation process of Etchells et al. (1973). In Experiment I, cucumbers (size no. 3, 3.8–5.1 cm diam) free from disease and mechanical injury were carefully hand washed and brined under laboratory conditions in four, 44-gal, pilot-scale brining tanks described earlier (Fleming et al., 1977). One month after brining, the fully fermented, essentially bloater-free, brine-stock cucumbers were used for storage studies. The brine analyses of these fermented cucumbers before further adjustments were: pH 3.5, 1.18% acid (as lactic) and 5.4% NaCl.

In Experiment II, cucumbers (size no. 2, 2.5–3.8 cm diam) were brined in a 1,000-bu commercial tank. The cucumbers were tanked by fluming in ca 7% NaCl; they were then covered with brine, drained, and re-covered with brine. The cucumbers received no other washing treatment. Brine analyses of the fully fermented cucumbers, ca 1 month after brining, were: pH 3.5, 0.58% acid (as lactic), and 6.1% NaCl.

Salt-stock cucumbers, prepared as described above for Experiments I and II and free of visible injury and of uniform size, were thoroughly mixed and separated into four lots. Two lots of cucumbers with sufficient brine to cover them were adjusted to 11.4% w/v NaCl and two lots were adjusted to 5.5% NaCl. Also, lots of cucumbers from each salt concentration were adjusted with NaOH or lactic acid to pH 4.00 or 3.5 ± 0.05 in Experiment I, and pH 3.8 or 3.3 ± 0.05 in Experiment II. The design of Experiment II is illustrated in Fig. 1. Experiment I was designed similarly, but only two incubation temperatures were used.

The cucumbers were packed into 1-gal jars, 20 per jar in Experiment I and 25 per jar in Experiment II (pack-out ratio cucumbers:brine, ca 60:40 in each experiment), and placed into incubators at 15.5 and 26.6°C in Experiment I and 4.4, 15.5, and 26.6°C in Experiment II. At 3-month intervals for 12 months, duplicate jars from each treatment were removed, equilibrated to room temperature (24 ± 2°C) for 48 hr, and analyzed for firmness by use of a Magness-Taylor fruit pressure tester (FPT) equipped with a 0.79-cm tip, according to Bell and Etchells (1961). All FPT readings were made by the same individual. Adjective ratings corresponding to FPT readings (Etchells et al., 1973) were: for size no. 2 cucumbers, very firm (18 lb and above), firm (15–18 lb) and inferior (11–14 lb); for size no. 3 cucumbers, very firm (20 lb and above), firm (16–19 lb) and inferior (11–15 lb).

Brines were analyzed for polygalacturonase activity by the method of Bell et al. (1955).

A split-plot design was utilized in the layout of the experiments. Due to the lack of replicates for the pH and salt adjustment treatments, a pseudo-error structure was developed for the purpose of statistical analyses. Four replications, each consisting of five (Experiment I) or six (Experiment II) cucumbers, randomly selected from all jar-treatment combinations, were used to create the error structure for the appropriate test of main-plot and sub-plot effects. The resulting analyses yielded a mean square error (MSE) for sub-plots essentially the same as the residual MSE computed from the difference among individual cucumbers. The residual MSE was considered appropriate for the statistical tests.

Calcium chloride, to equilibrate at 0.1%, w/v, was added to the

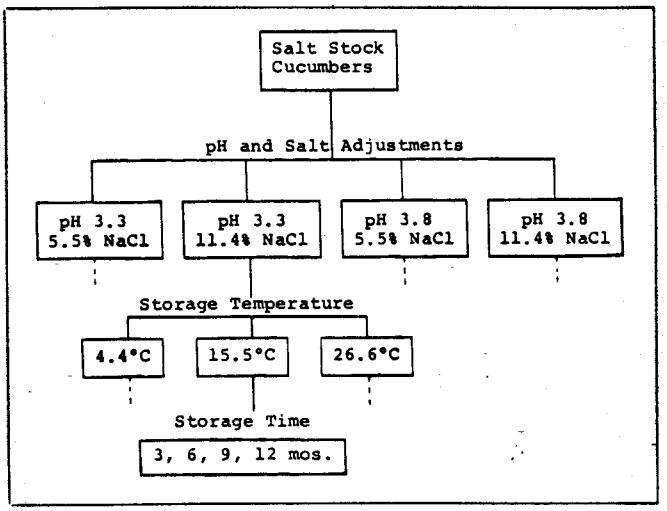

Fig. 1—Experimental design for storage study of salt-stock cucumbers.

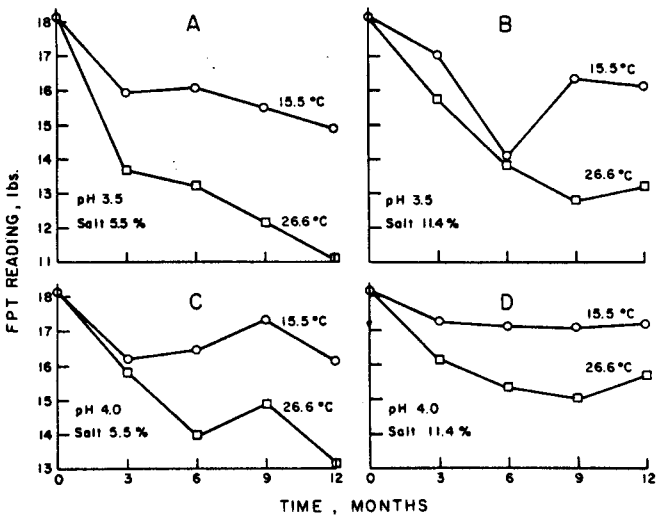

Fig. 2—Changes in firmness of size no. 3 salt-stock cucumbers during storage. See Experiment I.

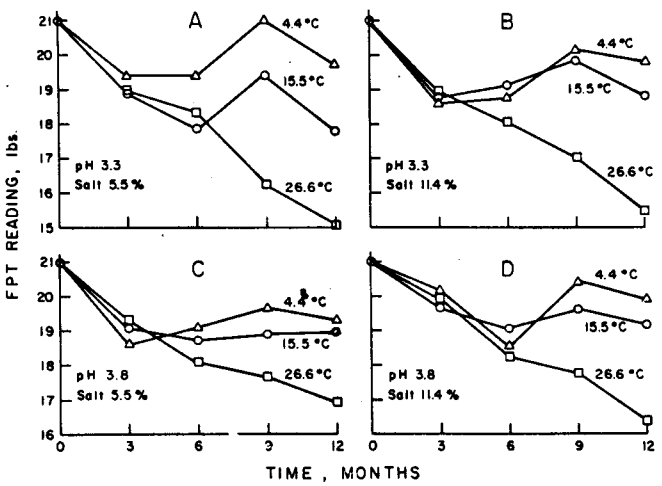

Fig. 3—Changes in firmness of size no. 2 salt-stock cucumbers during storage. See Experiment II.

cover brines of 16 additional 1-gal jars of cucumbers used in Experiment II. Duplicate jars of cucumbers with and without added calcium chloride were stored at 15.5 and 26.6°C at the pH and salt concentrations indicated in Figure 1. Pressure tests were made after 6 months' storage.

RESULTS

BRINES from Experiments I and II were "negative to weak" (ranging from 0–3 units) in polygalacturonase activity, when analyzed according to Bell et al. (1955), which we consider to be negligible in this study. Effects of four factors (pH, NaCl concentration, temperature, and time) on the firmness of brined cucumbers are shown in Figures 2 and 3. Generally, the factors similarly affected the cucumbers fermented under laboratory (Fig. 2) and commercial conditions (Fig. 3). Firmness retention was greatest at low temperature, high salt concentration, and high pH. By the end of the 12 months, the loss in FPT reading for cucumbers stored at 4.4°C was less than 2 lb, regardless of pH and salt concentration (Fig. 3). Firmness retention was slightly lower at 15.5°C, than at 4.4°C, but strikingly less at 26.6°C after 9 months' storage (Fig. 2 and 3). At 4.4 and 15.5°C, FPT readings became nearly constant after 3 months' storage; but readings steadily declined at 26.6°C (Fig. 3).

Effects of individual factors on firmness of the brined cucumbers when averaged over all other factors, and statistically significant interactions, are given in Table 1. Again, temperature was indicated to be the most important factor influencing firmness ($P \leq 0.01$, Table 2). The overall reduction in FPT readings due to storage at high (26.6°C) as compared to low (15.5°C) temperatures was 2.2 lb in Experiment I and 1.4 lb in Experiment II. Firmness loss was greater at low than at high pH values in both experiments ($P \leq 0.01$, Table 2). The overall reduction in FPT readings due to low pH was greater in Experiment I (1.5 lb) than in Experiment II (0.3 lb) (Table 1). Firmness loss was greater at 5.5 than 11.4% NaCl ($P \leq 0.01$ and 0.05 for Experiments I and II, respectively, Table 2). The overall reduction in FPT readings due to low salt concentration was 0.8 lb in Experiment I and only 0.2 lb in Experiment II.

Data from Experiment II were summarized to show the

Table 1—Effects of pH, salt, temperature, and time on the firmness of brined cucumbers[a]

Variable	FPT (lb) Exp I	FPT (lb) Exp II
pH		
3.3	–	18.5
3.5	14.4	–
3.8	–	18.8
4.0	15.9	–
Salt, %		
5.5	14.8	18.6
11.4	15.6	18.8
Temperature, °C		
4.4	–	19.5
15.5	16.3	19.0
26.6	14.1	17.6
Time, months		
0	18.2	20.9
3	16.0	19.2
6	15.0	18.6
9	15.1	19.0
12	14.7	18.1

[a] FPT readings for pH, salt, and temperature are averaged over the 3–12 month readings. Readings for 3, 6, 9 and 12 months, are averaged over pH, salt and temperature. Zero time readings were determined before any adjustments.

effect of temperature on the rate at which firmness was lost during storage (Fig. 4).

Addition of 0.1% calcium chloride to storage brines of cucumbers resulted in increased FPT readings after 6 months' storage at all combinations of temperatures, salt concentration, and pH tested (Table 3). The greatest increases in FPT readings due to calcium chloride addition occurred in cucumbers stored at pH 3.3 ($P \leq 0.01$ for three of four treatment combinations). At pH 3.8, only one treatment combination resulted in a significant increase in FPT reading due to calcium chloride addition (5.5% salt, 26.6°C, Table 3).

DISCUSSION

ALTHOUGH polygalacturonase activity in storage brines in this study was considered to be negligible, low levels of enzyme activity could contribute to the slow softening of cucumbers under prolonged storage. Also, the pectinolytic enzyme activity of the cucumber fruit might promote softening, particularly at low salt concentration and high storage temperature. Cucumbers contain a polygalacturonase (Pressey and Avants, 1975).

These storage studies indicated that the firmness of brined cucumbers can be maintained at 5.5% NaCl (20° salometer), provided the storage temperature is 15.5°C or lower and the polygalacturonase activity is negligible or within the limits used in these experiments. Thus, if proper conditions are maintained, it may be unnecessary to increase brine strength to between 11.4 and 17.6% NaCl (40–60° salometer) after the fermentation period, as has been the practice for many years. In geographic locations where freezing is not a problem, it may be possible to maintain brines below 8.4% (30° salometer) during storage. Further studies are needed to confirm these conclusions.

Storage temperature was the most important factor influencing firmness of brined cucumbers in this study. Storage temperature also has been shown to be a highly important factor influencing firmness of fresh pack cucumbers, the rate of firmness loss being particularly noticeable above ca 26.6°C (Pangborn et al., 1959; Nicholas and Pflug, 1960; Fellers and Pflug, 1965). At 1.1°C, the firmness of fresh pack pickles increased upon storage (Pangborn et al., 1959), which is consistent with our observation that firmness of brined cucumbers may increase at some point during storage (see e.g. Fig. 3, 4.4°C, the higher FPT readings at 9 and 12 months than at 3 and 6 months).

Firmness retention might be improved if low pH brine (e.g. pH 3.3) after fermentation is adjusted to ca pH 3.8. This adjustment can be made with NaOH, but partial adjustment with lime [$Ca(OH)_2$] up to about 0.07% (calcium equivalent of 0.1% $CaCl_2$), would improve firmness of the brine stock. Such adjustments [neutralization of lactic acid with NaOH or $Ca(OH)_2$] should be made carefully to avoid exceeding pH 4.0. It would be unwise to partially neutralize the fermentation acids in brines contained in tanks which leak excessively. Brine is customarily added to compensate for losses, but the added brine usually is not acidified; hence, acidity may be reduced below the level needed for preservation.

Design and type of materials used in the construction of brining tanks may influence the environmental conditions under which brine stock are held and, thus, the quality of the cucumbers. For example, underground storage tanks should maintain brined cucumbers at a fairly uniform temperature, reducing seasonal extremes due to ambient temperatures. Thus, cooler brine temperatures in summer would benefit product firmness while warmer temperatures in winter would allow the use of lower brine strengths without freezing damage. Although wooden tanks have been the

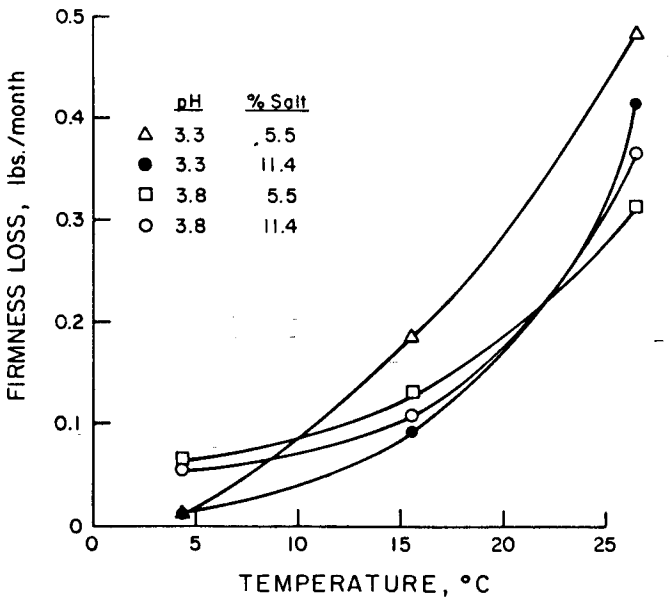

Fig. 4—Effect of temperature on firmness loss of salt-stock cucumbers during storage. Data based on Experiment II.

Table 2—Analysis of variance for factors affecting firmness of brined cucumbers

Source of variation	Degrees of freedom	Mean square
Experiment I		
pH	1	488.15**
Salt	1	282.04**
Temperature	1	1353.35**
Time	3	59.90**
pH X temperature	1	28.23*
Temperature X salt	1	42.05*
Time X salt	3	39.62*
Time X temperature	3	43.44*
Error	1118	7.048
Experiment II		
pH	1	56.93**
Salt	1	36.38*
Temperature	2	732.91**
Time	3	136.40**
pH X temperature	2	41.94**
Time X temperature	6	181.18**
Error	2254	6.51

* Denotes $P < 0.05$.
** Denotes $P < 0.01$.

Table 3—Effect of $CaCl_2$ addition on firmness of brined cucumbers[a]

	Average increase in FPT readings due to added $CaCl_2$			
	pH 3.3		pH 3.8	
	Salt, %		Salt, %	
Temp (°C)	5.5	11.4	5.5	11.4
15.5	4.1**	1.9**	1.0	.75
26.6	2.4**	1.0	1.5*	.52

[a] Used size no. 2 cucumbers, as described for Experiment II. Asterisks denote levels of significance for the increase in FPT readings of brined cucumbers to which $CaCl_2$ was added as compared to cucumbers without added $CaCl_2$; $P < 0.01$ (**), $P < 0.05$ (*).

primary storage vessel for brined cucumbers, some companies are testing and using coated concrete and fiberglass tanks to some extent. Both of these latter type tanks could be placed underground. In southern California, Spanish-type green olives are presently being fermented and stored in underground fiberglass tanks (Webster, 1978).

We attempted to predict the effects of the variables we studied on firmness of brined cucumbers. By response surface analysis, an equation for predicting firmness loss of brined cucumbers was developed, based on data obtained in Experiment II:

$$\frac{\text{FPT lb loss}}{\text{month}} = -0.47 + 0.042\,(^{\circ}\text{C}) + 0.00071\,(^{\circ}\text{C})^2 + 0.16\,(\text{pH}) - 0.0039\,(\%\ \text{NaCl}) - 0.014\,(^{\circ}\text{C} \times \text{pH})$$

The rate of firmness loss for each pH, salt, and temperature treatment (Fig. 4) was used as the dependent variable in a multiple linear regression analysis. Salt, pH, temperature, and selected interactions were the independent variables. Correlation coefficients between measured and predicted FPT readings were 0.81 and 0.86 for Experiments I and II, respectively. The above equation would be relevant only when polygalacturonase activity in the brine is negligible.

REFERENCES

Bell, T.A. and Etchells, J.L. 1961. Influence of salt (NaCl) on pectinolytic softening of cucumbers. J. Food Sci. 26(1): 84.

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

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

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

Ethcells, J.L., Bell, T.A. and Jones, I.D. 1955. Cucumber blossoms in salt stock mean soft pickles. Res. & Farming 13(1—4): 14.

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

Fellers, P.J. and Pflug, I.J. 1965. Quality of fresh whole dill pickles as affected by storage temperature and time, process time, and cucumber variety. Food Technol. 19: 416.

Fleming, H.P., Thompson, R.L., Bell, T.A. and Monroe, R.J. 1977. Effect of brine depth on physical properties of brine-stock cucumbers. J. Food Sci. 42(6): 1464.

Jones, I.D., Etchells, J.L. and Monroe, R.J. 1954. Varietal differences in cucumbers for pickling. Food Technol. 8(9): 415.

Monroe, R.J., Etchells, J.L., Pacilio, J.C., Borg, A.F., Wallace, D.H., Rogers, M.P., Turney, L.J. and Schoene, E.S. 1969. Influence of various acidities and pasteurizing temperatures on the keeping quality of fresh-pack dill pickles. Food Technol. 23(1): 71.

Nicholas, R.C. and Pflug, I.J. 1960. Effects of high temperature storage on the quality of fresh cucumber pickles. Glass Packer 39(4): 35.

Pangborn, R.M., Vaughn, R.H., York, G.K. II and Estelle, M. 1959. Effect of sugar, storage time and temperature on dill pickle quality. Food Technol. 13: 489.

Pressey, R. and Avants, J.K. 1975. Cucumber polygalacturonase. J. Food Sci. 40: 937.

Sneed, F.D. and Bowers, J.L. 1970. Green fruit characters of cucumber as related to quality factors in brine stock. J. Amer. Soc. for Hort. Sci. 95(4): 489.

Webster, J.R. 1978. Personal communication.

Ms received 9/28/78; revised 12/8/78; accepted 12/15/78.

Presented at the 38th Annual Meeting of the Institute of Food Technologists, Dallas, TX, June 4-7, 1978.

Paper no. 5637 of the Journal Series of the North Carolina Agricultural Experiment Station, Raleigh.

We thank the Mount Olive Pickle Company, Mount Olive, NC for providing cucumbers and other supplies. We appreciate the helpful advice and continued interest of T.A. Bell, formerly of our laboratory. We thank D.D. Hamann, Dept. of Food Science, North Carolina State University, for helpful discussions.

This investigation was supported by a research grant from Pickle Packers International, Inc., St. Charles, Illinois.