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Over-and Underpasteurization of Fresh Cucumber Pickles

R. C. Nicholas and I. J. Pflug
Food Science Department, Michigan State University, East Lansing, Michigan

SUMMARY

A single variety of cucumber was used to study the effect of heat on the pickle quality factors of texture, enzyme inactivation, and internal damage. The cucumbers were packed within 24 hr of harvest and heat-processed at 150–201°F for 7–166 minutes (F_{180} equivalent minutes from 0.01 to 220, $z = 18°F$). The product was evaluated immediately after heat processing and after 1, 10, 40, and 188 days at 75°F. The pickles were pressure-tested and cut to determine internal damage, and the covering brine was tested for peroxidase activity.

In all treatments, pressures were significantly lower for the heat-processed pickles than for the raw cucumbers. Pressure was maximum at an F_{180} of about 2 min, and then decreased with increasing process time. The F_{180} for a given amount of softening appeared to be an exponential function of temperature; the negative reciprocal of the slope of the softening curve (z) was about 19°F. At F_{180}'s less than 2 min, measurable peroxidase activity was obtained and the pressures decreased slightly with decreasing F value and with increasing storage time. Internal damage, largely carpel separation, was evident when the F_{180} exceeded about 2 min, and increased with the severity of the heat process. Peroxidase inactivation proceeded in accordance with established principles.

INTRODUCTION

In the manufacture of fresh cucumber pickles, it is axiomatic that underpasteurized pickles show bacteriological spoilage and that overpasteurized pickles are softened by the heat treatment. These generalized notions (which are, in fact, definitions of over- and underpasteurization) describe the problem of selecting an optimum heat process that will ensure a low spoilage rate but retain crisp texture.

This paper reports the effect of different heat processes as measured by pressure test, peroxidase inactivation, and internal damage. The range of processes was from a minimum not expected to prevent microbiological spoilage to a maximum expected to produce significant softening.

REVIEW OF LITERATURE

The principal work giving experimentally determined lethalities of cucumber pickle spoilage organisms is that of Anderson *et al.* (1951), who found z's, depending on the experimental conditions, in the range of 12.5–19°F. Esselen *et al.* (1951), in their review of the bacteriological problem, calculated lethalities with an assumed z of 18°F. Their studies showed that an F_{180} of 2.8 min for whole fresh cucumber pickles "was required to prevent spoilage and the development of off flavors due to enzyme action." This recommendation is in general agreement with that of Etchells and Ohmer (1941).

The significance of enzyme activity has been reviewed by Nebesky *et al.* (1951). Here, and elsewhere (Kaplan *et al.*, 1949; Labbee, 1952), a case is made for using peroxidase inactivation as an inferential test of flavor preservation; inactivation of the generally more resistant peroxidase system provides some assurance that other systems have been inactivated.

Kaplan *et al.* (1949) showed that peroxidase inactivation proceeds as a first-order reaction, and therefore is amenable to analytical treatment in the same manner as bacterial spoilage; their reported z for peroxidase inactivation is 20°F.

Loss of texture, a quality factor as elusive as flavor, was measured in pickles as a function of heat process by Nagel and Vaughn (1954) in a study of salt-stock pickles not primarily concerned with texture loss. They showed that the logarithm of force, measured with a fruit pressure tester (Magness and Taylor, 1925), was linear with time at a given temperature; they investigated several temperatures in the range 160–200°F. Joffe (1952) examined the loss of firmness in whole fresh cucumber pickles as a function of the heat process and found that the logarithm of the pressure could be fitted to a straight-line curve when plotted against equivalent process time. The best fit of his data showed a z of softening of 30°F.

It is beyond the scope of this paper

to discuss the relationship between texture and force measurements, and between flavor and peroxidase activity. But if these quality factors and bacterial spoilage are mathematically expressible in terms of temperature coefficients of the several reactions, then it should be possible to calculate an optimum process.

EXPERIMENTAL

Pickling cucumbers, variety SMR 18, 1–1½ in. in diameter, all harvested from the same field on August 12, 1960, were prepared the next day in lots large enough to make 16 quarts of fresh whole cucumber pickles, according to the following procedure: The cucumbers were washed 5 min in cold water in a tumble-action washing machine; packed by weight (21 oz) in quart jars; covered with hot brine (125–135°F, 1.4% acetic acid, 5.0% salt); spiced (courtesy of Wm. J. Stange Company, Inc.) with 1 ml of a 1:100 dilution of dill oil concentrate; closed with screw-on caps; heated in a constant-temperature water bath; cooled in a 90°F water spray; and cased and stored at about 75°F until examined. Table 1 gives the processing schedule and the calculated sterilizing value of the various treatments.

Pressure tests. All pressure measurements were made in the center of one of the prominent lobes of the pickles with a mechanical recording pressure tester (Pflug *et al.*, 1960) equipped with a Magness-Taylor fruit-pressure-tester tip 5/16 in. in diameter and operated at a plunger speed of 6.48 in./min. Pressure changes during storage were followed by making readings from each heat treatment at five times during storage. At each storage time 20 pickles were selected non-randomly from the contents of two jars (average 28 pickles); nubbins, crooks, under- and oversized pickles were not tested. The first pressure test, designated zero days, was made, depending on the treatment, between ½ and 3½ hr after the end of the heating period (average time was just over an hour); the second pressure test, designated 1 day, was made between 21½ and 24½ hr after the end of the heating period; the third was made 10 days after processing; the fourth, designated 40 days, was made between 37 and 42 days after processing, depending on the treatment; the fifth, and last, test was made 188 days after processing.

Internal damage. The pickles were examined for internal damage 13 and 191 days after processing. Each pickle in two jars from each treatment was cut crosswise into about a dozen slices, and the defects subjectively classified as carpel separation, seed cavity, or miscellaneous. Carpel separation means the separation of any or all three of the carpels. This damage may be what Nagel and Vaughn referred to as gas pockets (Nagel and Vaughn, 1954). Seed-cavity damage refers to any pronounced softening or hole in the seed cavity not involving separation of the carpels. Miscellaneous includes all other damage: rot, for example. The extent of damage varied from pickle to pickle, but was recorded only as the number of pickles involved.

Peroxidase activity. Peroxidase activity was determined by Labbee's method (1952), in which the activity of the sample is determined by comparison against a set of potassium dichromate color standards arranged on a scale of 1–10, which is approximately linear with the logarithm of the potassium dichromate concentration; 10 is high activity. Readings were estimated to the nearest ½ standard number. Tests were made of duplicate 5-ml portions from the combined covering brines from each pair of jars taken for pressure testing on the 40th day after processing and also from each pair of jars for cutting and pressure testing, respectively at 191 and 188 days after processing. A distilled water blank was run with each set of samples (several determinations can be run simultaneously). Since the scale is logarithmic, the activity numbers were not adjusted by subtracting the corresponding reading of the water blank. The activity numbers of the blanks were 1.5 or less.

ANALYSIS

Softening was assumed to be a logarithmic function of heating time, t, at a particular temperature, T, given by

$$\log P = -t/s(T) + \log P_o \quad [1]$$

where P is the average pressure determined by the mechanical pressure tester of fruit initially having an average pressure of P_o, and where s(T), an arbitrary constant, is the heating time that would reduce the pressure to 0.1 its initial value.

The decimal pressure reduction time, s(T), was assumed to vary with temperature according to

$$\log s(T) = -(T - T_o)/z + \log s_o(T_o) \quad [2]$$

where $s_o(T_o)$ is the decimal pressure reduction at a reference temperature, T_o. Equation 2 holds, *mutatis mutandis*, for any other criterion, such as the s(T) for 50% pressure reduction. The slope of this curve, $-1/z$, gives the variation in softening with temperature. The similarity of equations 1 and 2 to the equations governing logarithmic bacterial destruction is obvious.

The softening time in equation 1 is time at temperature T, or its equivalent. Since, in general, the temperature in the jar is constantly changing during heating, the equivalent time must be calculated. The softening value (analogous with sterilizing value) accumulated during heating, $U_{heating}$, was calculated from the exponential integral. The total softening value, U_{total}, was calculated by $U_{total} = U_{heating}/\rho$. Values of ρ were determined, by extrapolation to lower values of m + g, from Ball's and Olson's (1957) tables of ρ vs. z for various values of m + g.

The heating rates, f_h, and lag factor, j, used to calculate the equivalent minutes (Ball and Olson, 1957), were average values based on Joffe's (1959) data and additional heat penetration measurements made as part of this study. Joffe (1959) showed, and his result was verified by the present work, that heating rates in whole fresh cucumber pickles decreased with increasing heating-medium temperature and that lag factor, j, was constant. Values used were $j = 1.00$ and $f_h =$ 23.2, 23.2, 23.2, 22.1, 21.0, 20.0, and 19.3 min, corresponding to the 7 processing temperatures given in Table 1. The average initial temperature was 86°F.

The data were fitted by iteration: a z was assumed; the best fit of the logarithm of the pressure readings against equivalent softening time at each processing temperature was calculated by the method of least squares; the time to reduce the pressure to 10 lb was calculated from the least-squares line for each processing temperature (10 lb was selected as a suitable criterion because pressures were observed above and below 10 lb); the logarithms of these times were plotted against processing temperature, and the best line (similar to equation 2) was determined by least squares; the z derived by this last calculation was compared with the assumed z.

RESULTS

Fig. 1 shows the equivalent minutes to reduce the pressure to 10 lb. This curve was calculated from the average pressure measurements at 10 days after processing, at processing temperatures 170°F or greater, and at processing times greater than F^{18}_{180} of 1 min. The average pressures were first adjusted by rejecting all readings

± 2 standard deviations from the mean; the maximum correction was 0.34 lb. At 10 days after processing, it was argued, the salt and acid equilibrium between cucumbers and brine was nearly established, but at zero and 1 days it was not, and at longer times any storage effects on pressure would be included in the results. At processing temperatures of 150 and 160°F, the times were not long enough to show appreciable softening (see Table 1). At process values less than 1 min, there was little softening from heat, and, as discussed below, some other softening effect was operative. On the last iteration step an assumed z of 19.0°F returned a z of 19.2°F.

Fig. 2 shows the 20 average pressure readings used to compute the z of softening plotted against equivalent minutes at 180°F. The line drawn through the points is based on the average slope and intercept of the five lines (one at each temperature) corresponding to equation 1. The intercept, P_0, is the expected pressure when t is zero. This pressure is less than the raw-product pressure (18.33 lb) and may be the expected pressure that results from simply putting cucumbers in the salt-acid brine without any cooking.

Fig. 3 shows the change in peroxidase inactivation rate with temperature. Equations 1 and 2, in which log P is replaced by the peroxidase activity number, describe the assumptions made to arrive at the curve. The iteration process, beginning with a z of 20°F (Kaplan *et al.*, 1949), gave 18.2°F, which in turn gave 18.0°F. The extrapolated curve is given to show how much time would be required at the lower processing temperatures to reduce the activity significantly. The data used in determining the z for peroxidase were the averages of the two determinations at 188 and 191 days after processing. The activities measured at 40 days were higher, on the average, but linearly related to the average of the 188- and 191-day activities. The curve, showing the equivalent minutes to reduce the activity to 5, is based on activities between 8.6 and 1.5 when the next-longest heating time showed lower activity and when the first reading of 1.5 (which is approximately equal to the water blanks) occurred at a reasonable time. The results at process temperatures of 150 and 160°F showed no significant reduction in activity, and were not used. The activity numbers at a processing temperature of 205°F were 6.6, 1.5, 1.5, and 1.5, and were not used in determining z, but the first two are plotted in Fig. 4, which shows the activity as a function of equivalent minutes. The line in Fig. 4 is based on a weighted average of the slopes and intercepts of the four equations, one determined for each processing temperature, corresponding to equation 1.

Fig. 5 shows the fraction of defective cucumbers as a function of maximum temperature reached in the jar. The suggestion of gas pockets (Nagel and Vaughn, 1954), related, certainly, to dissolved gas, provides a theoretical basis for plotting these data against maximum temperature; moreover, efforts to fit the percents defective to equivalent minutes for any z proved fruitless. The plotted points are the averages of the two determinations made 13 and 191 days after processing. By defective is meant the number showing carpel separation plus a few showing seed-cavity damage that was judged to be caused by heat. More defective cucumbers were found at the first examination than at the second; however, two different people made the examinations.

Table 2 shows the average pressure (data grouped by severity of the process) as a function of storage time. A difference between means of about 0.6 lb is required for significance at the 5% level. There were no significant changes after the 10th day; the greatest changes took place in pickles processed at small F_{180} values and occurred between the zero and 1st days. Taken as a whole, the changes with storage time were small, but at all

Table 1. Process schedule and data summary.

Process schedule: Temp. (°F)	Process schedule: Time (min)	Max. temp. reached in jar (°F)	Sterilizing value, F^{18}_{180} (min)	Average[a] pressure (lb) at days: 0	10	188	Peroxidase number
150	19	133	0.010	16.8	15.8	15.4	8.9
150	35	147	0.18	16.5	14.4	15.6	8.6
150	92	150	1.3	15.5	15.4	14.5	8.5
160	14	130	0.012	17.0	13.9	15.5	8.5
160	28	148	0.13	16.1	14.4	15.6	8.8
160	40	159	1.2	14.8	14.2	15.3	8.5
170	11	130	0.011	17.5	15.8	16.7	8.5
170	16	147	0.10	17.0	14.8	16.3	8.5
170	27	162	0.98	17.0	15.8	15.2	8.5
170	31	165	1.6	16.8	16.1	16.0	8.5
170	63	170	8.9	15.8	14.8	14.6	6.5
170	104	170	20	13.0	14.9	14.7	5.0
170	166	170	38	13.6	13.1	13.6	1.5
180.3	9	130	0.026	17.3	15.2	15.0	8.5
180.3	13	147	0.11	16.6	15.6	15.8	8.6
180.3	19	162	0.65	15.8	15.6	15.5	8.5
180.3	23	168	1.6	14.5	15.9	15.6	8.0
180.3	42	179	14	14.6	14.2	14.2	6.4
180.3	63	180	35	13.4	14.0	12.7	4.0
180.3	95	180	68	12.3	12.5	12.1	1.5
189.8	7	124	0.011	16.9	15.6	15.8	8.9
189.8	10	143	0.062	16.7	15.9	16.5	8.8
189.8	15	162	0.65	15.2	15.5	15.6	8.5
189.8	20	173	2.5	16.3	16.0	16.1	8.0
189.8	33	185	21	14.0	14.3	11.0	3.7
189.8	48	188	63	12.4	11.8	10.7	1.5
189.8	66	190	130	9.6	10.3	10.4	1.5
196.6	16	173	2.3	15.0	15.5	15.1	7.6
196.6	25	189	28	13.4	13.4	13.5	4.0
196.6	33	194	63	10.7	11.5	10.8	1.5
196.6	44	196	140	8.7	8.9	8.5	1.6
204.5	15	179	4.3	16.4	15.1	14.5	6.6
204.5	21	192	29	13.0	12.4	14.0	1.5
204.5	27	198	90	10.4	11.6	12.5	1.5
204.5	35	202	220	9.9	8.5	8.3	1.5

[a] Twenty pickles in each treatment.

Table 2. Average[a] force (lb) as a function of process and storage time.

No. of treatments combined	F^{18}_{180} range (min)	Storage time (days after processing): 0	1	10	40	188
5	0.011–0.026	17.10	15.65	15.26	15.14	15.48
5	0.062–0.18	16.60	15.88	15.02	15.37	15.96
5	0.65 –1.2	15.67	16.09	15.85	15.71	15.24
5	1.6 –4.3	15.78	16.03	15.83	15.31	15.47
8	8.9 –38	13.85	14.65	13.88	13.95	13.65
7	63 –220	10.57	11.00	10.75	10.64	10.47

[a] Twenty pickles in each treatment.

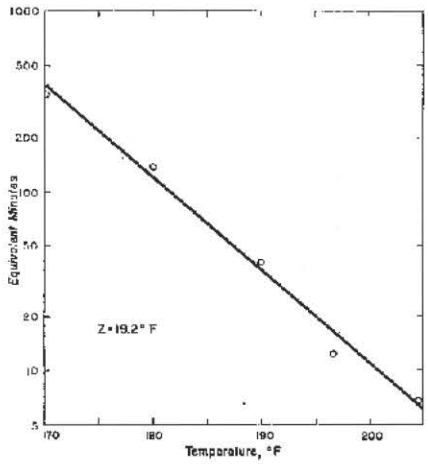

Fig. 1. Equivalent minutes at processing temperature to reduce the average pressure to 10 lb.

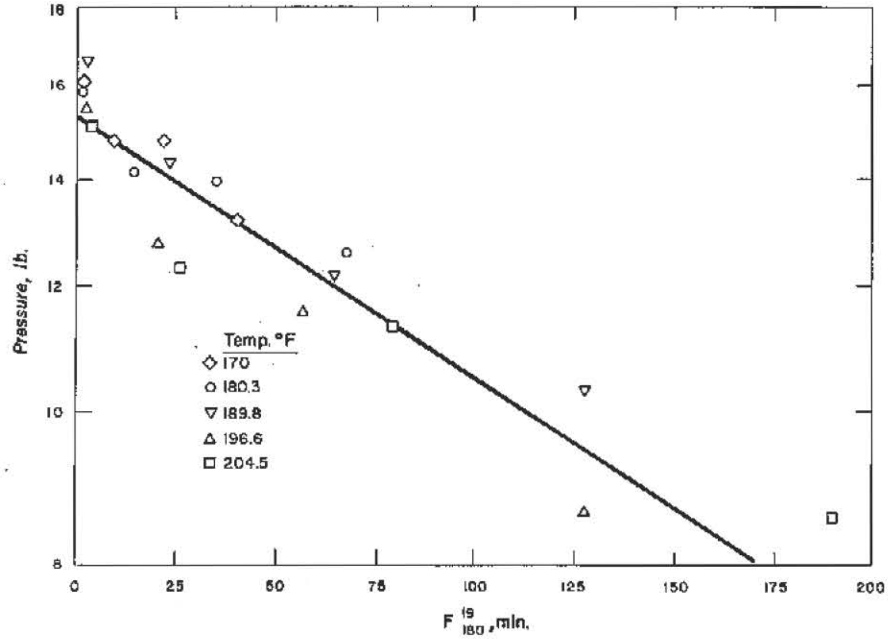

Fig. 2. Average pressures at 10 days as a function of equivalent minutes at 180°F.

treatments and at all storage times the average pressures were significantly lower than the raw-product pressure. Perhaps the best summary of the changes in pressure with storage, as a function of process time, is the relation between change in average pressure during storage (188-day minus 0-day) and sterilizing value. On a scatter diagram of the loss in average pressure during storage plotted against the logarithm of the sterilizing into two groups, those below F_{180} of 4 min, and those above. The correlation value (F^{18}_{180}), the points seemed to fall coefficient of pressure change and the logarithm of the sterilizing value (F_{180} < 4 min) was 0.63, 95% confidence limits 0.36 to 0.89. The correlation coefficient for pressure loss and log F_{180} for $F_{180} > 4$ min was 0.28, not significantly different from zero. Pressure loss on storage seems to be a linear, decreasing function of sterilizing value up to values of 4 min, and independent of sterilizing value beyond 4 min.

DISCUSSION

No claim is advanced that softening has been conclusively demonstrated to proceed as a first-order reaction. Nevertheless, the fit (Fig. 1) is good enough to encourage the view that softening, or at least that aspect of softening that is measured by a mechanical recording pressure tester, follows a first-order law in the temperature region studied. The 95% confidence interval on z, as determined from the variance of the five 10-lb points, is from 15.7 to 24.7°F, and is probably different from Joffe's (1959) value of 30°F. It is possible that z is a function of cucumber variety or season or both. The authors believe that the curves of texture loss are good enough to use, provided z is known for the product, as a predicting equation for softening or, if z is not known, as a tool to compare varieties in their resistance (and therefore suitability) to heat processing.

The z of the peroxidase inactivation curve (Fig. 3) is in agreement with that of Kaplan *et al.* (1949).

It should be mentioned that only one jar in this study spoiled, one of the 16 heated 35 min at 150°F; however,

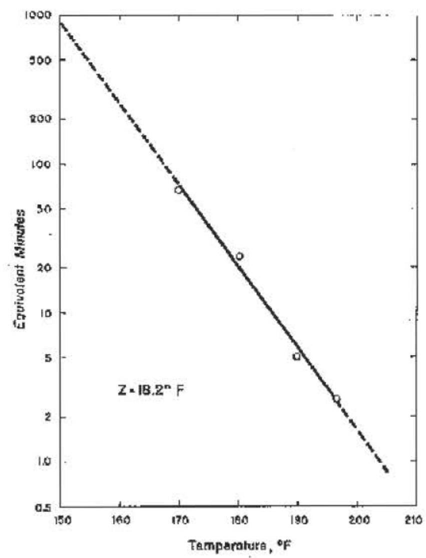

Fig. 3. Equivalent minutes at processing temperature to reduce the peroxidase activity to 5.

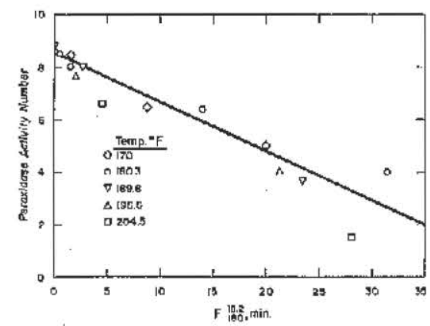

Fig. 4. Average peroxidase activity at 6 months as a function of equivalent minutes at 180°F.

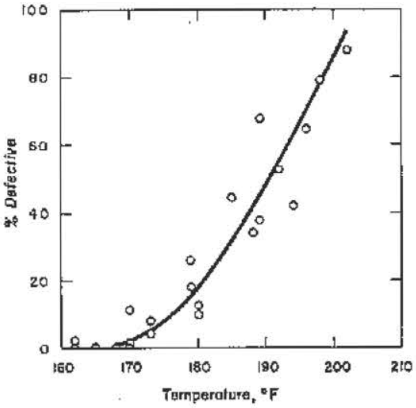

Fig. 5. Percent of defective cucumbers as a function of maximum temperature reached in the jar.

the authors are not recommending such low processes.

The loss of texture on storage—except at the very lowest sterilizing values, which are not recommended in any case—is too small to worry about.

The differences among the z's for softening, bacterial destruction, and enzyme inactivation are not large enough to warrant any blanket statement about possible benefits from higher temperatures and shorter times; in fact, the occurrence of carpel separation, which appears to be related to maximum temperature reached in the jar rather than sterilizing value, suggests lower processing temperatures.

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