METHOD FOR DETERMINATION OF FIRMNESS IN CUCUMBER SLICES[1]

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ABSTRACT

A punch and die assembly was adapted to the Instron UTM for determination of firmness of mesocarp and endocarp tissues in cucumber slices. A cylindrical punch 0.315 cm diameter (0.200 to 0.635 cm diameter tested) and a cucumber slice thickness of at least 0.48 cm were found to be suitable for the method developed. Penetration force was about five times greater for mesocarp than endocarp in 4 to 5 cm diameter cucumbers. Mesocarp and endocarp were firmer near the stem end than near the blossom end of cucumbers. Force readings also declined for both tissues with increase in fruit diameter from about 2 to 6 cm. Single slices taken from the center of 20 cucumbers and punched once each at specified locations in the mesocarp and endocarp provided sufficient sampling to limit the coefficient of variation to about 5%. The correlation coefficient between sensory analysis for firmness and puncture force readings of fermented cucumber slices was 0.88.

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INTRODUCTION

Texture is an extremely important quality attribute of cucumber pickles. Consumers prefer a firm, crisp, and crunchy product. Both sensory and instrumental methods have been used to determine textural properties in cucumbers and cucumber products. The Magness-Taylor fruit pressure tester (FPT) (Magness and Taylor 1925) has been the most widely used instrument for routine determination of firmness of whole cucumbers. It has been used to determine cultivar variation in firmness of fresh cucumbers (Jones *et al.* 1954) as well as effects of brining (Bell *et al.* 1955; Thompson *et al.* 1979) and pasteurization (Jones *et al.* 1941; Monroe *et al.* 1969) on the firmness of cucumber products. The FPT has usually been used to measure the force required to penetrate the skin and flesh of the whole cucumber.

The texture of cucumbers is influenced by the nature of its constituent tissues which may be grouped into exocarp (skin), mesocarp (fleshy parenchyma), and endocarp (seed or locule area). Thus, penetration of the whole fruit with an instrument such as the FPT may not provide textural data representative of the various tissue types. This problem exists also with instruments more sensitive than the FPT, such as the Instron UTM (Breene *et al.* 1974), which have been used in penetration tests of whole cucumbers.

Attempts to distinguish textural properties of specific tissues within the cucumber have been made. Skin toughness of fresh cucumbers has been measured with the Chatillon Spring Puncture Tester to predict quality of the brined cucumbers (Sneed and Bowers 1970) and with the Instron UTM to predict resistance of the skin to puncture, abrasion, and breakage during mechanical harvesting and handling of cucumbers (Su and Humphries 1972).

Determinations that have been made in relation to textural properties of the cucumber fruit interior include: carpel strength with the Instron UTM (Marshall *et al.* 1975); Texture Profile Analysis of cucumber slices with the skin on and with the skin off (Breene *et al.* 1972; 1974; Jeon *et al.* 1973); and anatomical dimensions and characteristics of interior cells and structures (Goffinet 1977; Miller and Morey 1977).

The importance of distinguishing textural changes in different tissues is emphasized by the occurrence of soft centers in cucumbers, particularly the larger sizes. This problem, which is of commercial importance, is thought to be associated with the breakdown of the seed area tissue by a natural endopolygalacturonase during latter stages of fruit development (McFeeters *et al.* 1980). Fleming *et al.* (1978)

distinguished firmness of mesocarp and endocarp tissue by sensory analysis, and reported that the firmness of both tissue types was improved by the addition of calcium acetate. Hudson and Buescher (1980) distinguished firmness of pericarp (exocarp + mesocarp) and endocarp tissues by independent punches with a U. C. Fruit Firmness Tester, and reported that calcium chloride prevented soft center development in large, whole cucumbers. Neither of these methods was considered to be sufficiently sensitive for studies to determine effects of constitutive enzymes of the cucumber and various processing treatments on firmness of mesocarp and endocarp tissues.

The objective of our research was to develop a sensitive and reliable punch method for distinguishing the firmness of mesocarp and endocarp tissues of cucumber slices.

EXPERIMENTAL

The Instron UTM was equipped with the hardware shown in Fig. 1. The flat plate mounted on the force transducer has a recess that is 2.23 cm in diameter for a depth of 0.43 cm and then narrows to 1.58 cm diameter for a depth of 1.85 cm. There is a drain hole at the bottom of the recess. Various dies can be inserted into the recess so that the die surface is even with the surface of the plate. Die hole diameters are 0.0051 cm larger than the corresponding punches. There is 1.05 cm clearance between the bottom of the die and the bottom of the recess, which is connected to a drainage tube. A 2 kg compression force transducer (Fig. 1) was found to have sufficient capacity for all tests. Two kg and 0.5 kg full-scale settings were used for the mesocarp and endocarp tissues, respectively. The stop on the crosshead allowed the plunger to completely penetrate the slice and just enter the die. A crosshead speed of 20 cm/min and chart drive speed of 50 cm/min were used as the standard conditions for the tests to be described. Maximum penetration force was the only parameter from the force-distance curves used for analysis.

'Chipper' cucumbers from a N. C. Agricultural Research Service experimental farm were hand picked within a 6-week period from the same plot. Cucumbers used were uniformly shaped and free from disease and mechanical injury. The cucumbers were graded by diameter to commercial size numbers 1, 2, 3, and 4 (up to 2.70, 2.70-3.81, 3.81-5.08, and 5.08-5.72 cm diameter, respectively).

For sources of variation in firmness within cucumbers, number 3 size fresh fruits were cut transversely into stem end, middle, and blossom end sections of approximate equal length (Fig. 2). The slices

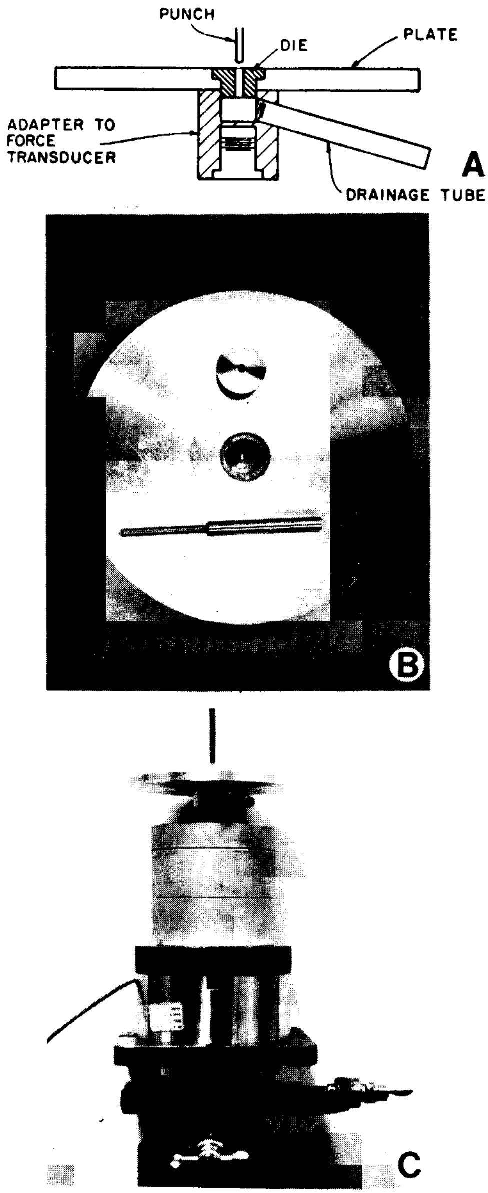

FIG. 1. APPARATUS USED IN THE PUNCH AND DIE TESTS

(A) Side, cut away view of plate with punch, recess and die; (B) Overhead view of plate with flat-ended punch, recess and die; (C) Plate mounted on force transducer that is bolted to an adjustable milling table were punched according to scheme I (Fig. 3) or scheme II (Fig. 4). Only fruit with 3 carpels as shown in Fig. 4 were used in this study. The carpels are distinct in the endocarp (seed area) as each can be seen in relation to its placentae. Carpellary distinction is less obvious in the mesocarp tissue. For purposes of this paper, therefore, we use the term "carpels" in relation to divisions in the endocarp and "lobes" in relation to widened areas of the mesocarp. For scheme I (Fig. 3), 4 slices were cut from the middle section of 15 cucumbers. The skin of the cucumbers was marked so that firmness determinations could be related to original positions in the fruit. This scheme was designed to determine variations in firmness of mesocarp as determined transversely from skin to endocarp, and variations among lobes of the fruit. For scheme II (Fig. 4), 3 slices were taken from each of the 3 sections of 30 cucumbers. No attempt was made to relate lobe and slice firmness to original positions in the fruit. Rather, this scheme was designed to determine variations in firmness due to slice within section, section, and among cucumbers.

For variation in firmness of fresh cucumbers due to size, 25 fruit of each of 4 sizes were punched at location 2 in 1 lobe of the mesocarp and once in the adjacent endocarp region (Fig. 4). The firmness of a corresponding lot of fermented cucumbers also was determined.

All determinations were made with a 0.315 cm diameter punch and a 0.48 cm thick slice.

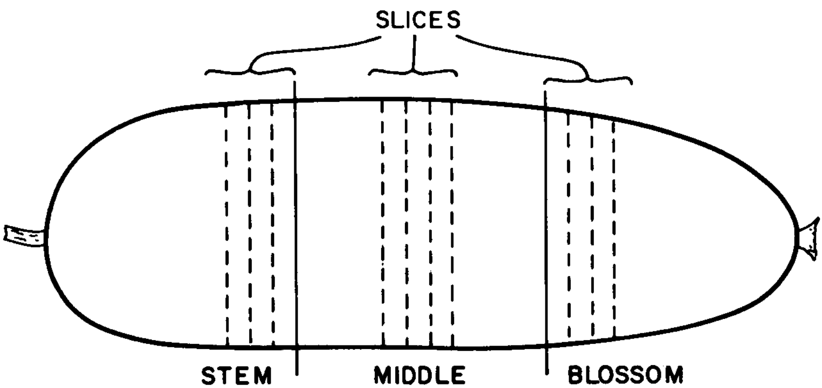

FIG. 2. POSITIONS OF SECTIONS AND SLICES TAKEN FROM CUCUMBERS

A hand-operated food slicer was modified to produce uniform slices of desired thickness. Slice thickness was verified by a micrometer to within 0.08 cm of the desired setting. Cucumber slices with thickness ranging from 0.32 to 0.95 cm, in 0.16 cm increments, were cut from the middle section of 90 fresh cucumbers (4.45 to 5.08 cm diameter) for tests to determine a suitable thickness for further studies. The slices were punched once in the mesocarp (location 2, Fig. 4) and once in the endocarp.

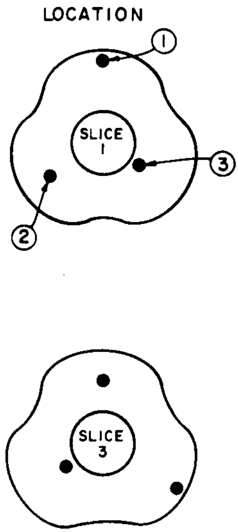

FIG. 3. SAMPLING SCHEME I FOR PENETRATION FORCE READINGS IN THE MESOCARP TISSUE OF SIZE NUMBER 3 CUCUMBER SLICES

Four adjacent slices were taken from the middle section of the cucumbers with lobe and slice orientation fixed, and punches were made in the locations indicated.

Effect of punch size on force readings was determined using 4 flat-ended cylindrical plungers (0.200, 0.315, 0.475, and 0.635 cm diameter) on 0.48 cm thick slices cut from the middle section of 12 size no. 3 cucumbers. Single punches were made in both the mesocarp (location 2) and endocarp of each of 4 slices (one punch size per slice) taken from the middle section of each cucumber.

An experienced, 5-member panel rated fermented cucumber slices which had undergone various prebrining heat treatments involved in a companion study and which varied widely in firmness. The firmness ratings were determined by biting through the slices. Each panel member tested at least three slices per treatment. Firmness was judged on a 10-point scale: 10-9 = excellent (firmest), 8-7 = good, 6-5 = fair, 4-3 = poor, and 2-1 = poor to unacceptable. Each treatment was rated at two different sessions. Slices from each treatment were also tested on the Instron UTM as decribed above.

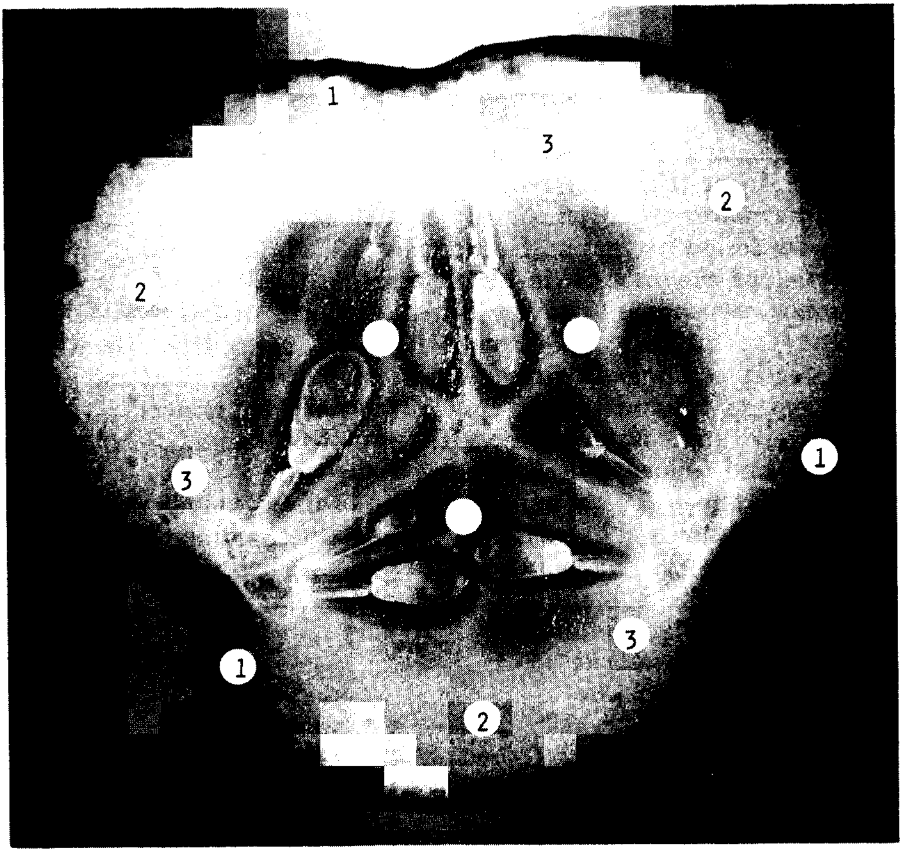

FIG. 4. SAMPLING SCHEME II FOR PENETRATION FORCE MEASUREMENTS IN THE MESOCARP AND ENDOCARP OF SIZE NUMBER 3 CUCUMBER SLICES

RESULTS AND DISCUSSION

Slice Thickness

We found no statistically significant ($P > 0.05$) differences in penetration force among slice thicknesses ranging between 0.48 and 0.95 cm, for either mesocarp or endocarp tissues. At 0.32 cm thickness, however, penetration forces were significantly lower (P <0.01) in both tissues than those in the thicker slices. For purposes of the remainder of this study, we chose to use a slice thickness of 0.48 cm. A cucumber slice thickness of 0.48 to 0.64 cm is commonly used by commercial processors for such items as hamburger dill chips and sweet slices.

Punch Size

The relationship between maximum penetration force and punch area was linear (Fig. 5A), while that between penetration force and punch perimeter appeared slightly curvilinear (Fig. 5B). Similar results were found by Su and Humphries (1972), who studied rupture properties of cucumber skin by penetrating the fruit with a punch positioned perpendicular to the longitudinal axis of the cucumber.

Using the method of Bourne (1975) for calculating shear and compression coefficients with cylindrical punches, we found shear coefficients of 5.3 and 1.03 N/cm for mesocarp and endocarp tissues, respectively; and compression coefficients of 60.4 and 8.3 N/cm^2 for mesocarp and endocarp tissues, respectively.

Although any of several punch sizes can be used (as indicated by the relationships shown in Fig. 5), a 0.315 cm diameter punch was selected for further studies. This punch is small enough for positioning in defined locations of small and large cucumbers, and yet large enough to cause adequate scale deflection.

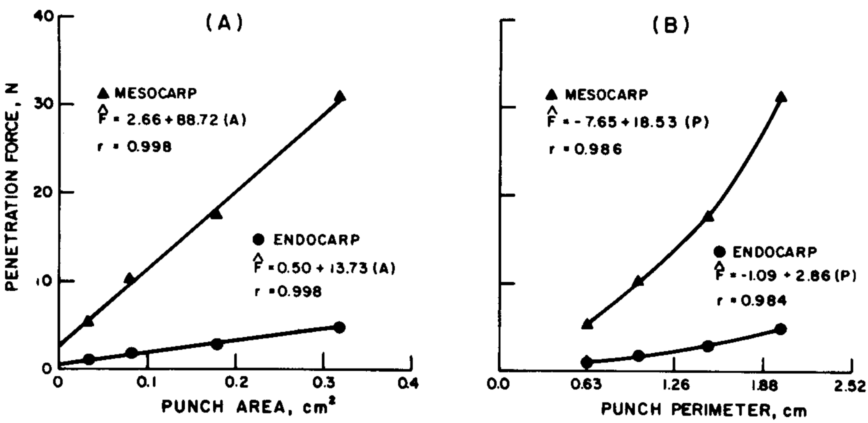

FIG. 5. EFFECT OF PUNCH CROSS-SECTIONAL AREA (A) And perimeter (B) On penetration force of mesocarp and endocarp in size number 3 cucumbers

Soures of Variation

When sampled according to scheme I (Fig. 3), there were no significant differences (P >0.05) in firmness among the 3 lobes of mesocarp tissue, or among the 4 adjacent slices, within size number 3 cucumbers. The tissue was firmer near the skin, however, and became progressively less firm toward the seed area (Table 1).

Table 1. Penetration force of the mesocarp and endocarp of fresh cucumber slices[1]

Tissue	Location[2]	Section		
		Stem	Middle	Blossom
Sampling scheme I				
Mesocarp	1		10.09[a]	
	2		8.21[b]	
	3		5.91[c]	
Sampling scheme II				
Mesocarp	1	11.73[a]	11.35[b]	11.21[b]
	2	9.46[c]	9.19[d]	9.03[d]
	3	6.37[e]	5.83[f]	5.66[f]
Endocarp	—	2.10[g]	1.79[h]	1.82[h]

[1]Numbers are expressed as Newton and are means of 60 punches for scheme I and 270 punches for scheme II, using number 3 size cucumbers. The two schemes were followed with separate lots of cucumbers. Means within rows and columns for each scheme with the same letter superscript are not significantly different (P >0.05) by Duncan's New Multiple Range Test

[2]Locations in mesocarp are 1 (near exocarp), 2 (center), and 3 (near endocarp) as shown in Fig. 3 for scheme I and Fig. 4 for scheme II

When sampled according to scheme II (Fig. 4), there were significant differences (P <0.01) among cucumbers and among the 3 sections of the size number 3 fruit for both mesocarp and endocarp tissues (Table 2). Force readings were about 5 times greater for mesocarp than endocarp tissue, so variations of the 2 tissues were determined independently. Significant variation existed among the 3 locations of mesocarp tissue tested. Thus, for further studies, force readings were taken only at location 2 (Fig. 3 and 4). Only 1 location was tested within each carpellary section of the endocarp. Overall, total variances for mesocarp tissue was partititoned as follows: 68% among cucumbers; 1.4% among sections; and 4.5% due to cucumber x section interaction (Table 2). For endocarp tissue, total variances were partitioned as follows: 53% among cucumbers; 5.3% among sections; and 11% due to cucumber x section interaction (Table 2). Breene *et al.* (1973), using compression tests, attributed greater firmness of cucumbers near the stem end to thicker skin and a larger ratio of mesocarp to endocarp tissue. Our data indicate, however, that both mesocarp and endocarp tissues are firmer at the stem end (Table 1).

The firmness of mesocarp and endocarp tissues varied inversely with cucumber size for fresh and fermented cucumbers (Fig. 6). The relationship was essentially linear for mesocarp tissue, but noticeably curvilinear for endocarp tissue.

Table 2. Analysis of variance for penetration force in cucumber slices[1]

		Tissue Type			
		Mesocarp		Endocarp	
Source	df	MS	F-ratio	MS	F-ratio
Cucumbers	29	42.629	30.44**	5.412	9.60**
Sections	2	12.883	9.20**	7.842	13.91**
Sections × cucumbers (error A)	58	1.400		0.564	
Slices (sections ×cucumbers)	180	0.718		0.161	
Carpels (slices × sections × cucumbers)	540	0.633		0.114	

[1] Penetration force was determined at location 2 of scheme II within the mesocarp of size number 3 cucumbers (Fig. 4)
**P ≤0.01

Mesocarp tissue was firmer in fermented than in fresh cucumbers for smaller sizes of fruit (Fig. 6). However, endocarp tissue was firmer in fresh than in fermented cucumbers of all sizes tested (Fig. 6). These relationships are suggestive of a potential value for distinguishing firmness differences by tissue type. The punch test should be particularly useful in studies on soft center development of brined cucumbers and in studies on brining treatments as they affect a particular tissue.

Determination of Sample Size

Although the punch test offers the versatility of distinguishing firmness of different tissues, it also results in variability among individual punches, which is largely an expression of variability within the product. Thus, in determination of an appropriate sample size for the punch test, one must consider the variance components that influence the sample mean. For cucumber slices, the variance of any mean firmness, $V_{\bar{x}i\cdots}$, can be represented as:

$$V_{\bar{x}i\cdots} = \frac{\sigma_c^{\,2}}{c} + \frac{\sigma_s^{\,2}}{c \times s} + \frac{\sigma_{error}\ (p+1)}{c \times s \times i \times p}$$

where σ_c^2 = cucumber variance, σ_s^2 = section variance, σ_{error}^2 = pooled slice and punch within slice variance, c = number of cucumbers, s = number of sections/cucumber, i = number of slices/ section and p = number of punches/slice.

In estimating the sample size required to fall within a desired variance range, one may substitute estimated variance components and reasonable combinations of numbers for c, s, i, and p in the above equation. The variance components for mesocarp tissue, based on data in Table 2, were estimated as follows:

$$\sigma_{error}^2 = \frac{\text{MS for i } (s \times c)}{(i-1)\ (s)\ (c)} + \frac{\text{MS for p } (i \times s \times c)}{(p-1)\ (i)\ (s)\ (c)} = 0.00516$$

$$\sigma_s^2, = \frac{\text{MS for c} \times s - \sigma^2_{error}}{9} = 0.155$$

$$\sigma_c^2 = \frac{\text{MS for c} - 9\,(\sigma_s^2)}{27} = 1.527$$

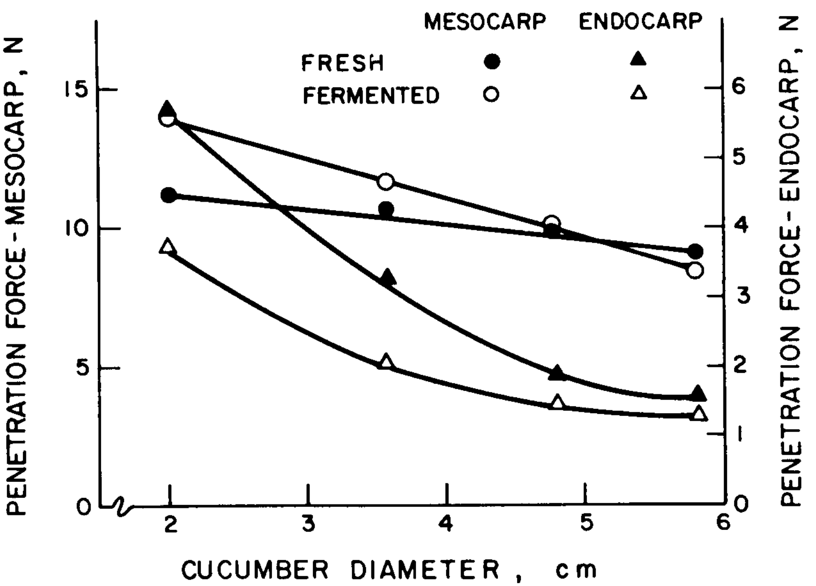

FIG. 6. EFFECT OF CUCUMBER SIZE ON PENETRATION FORCE IN FRESH AND FERMENTED CUCUMBERS (punch diameter, 0.315 cm)

Table 3. Effect of sampling on coefficient of variation

Tissue	Total Number of Punches	Lobes or Carpels × Slices × Sections × Cucumbers	Coefficient of Variation
Mesocarp	540	3 × 3 × 3 × 20	3.04
	60	1 × 1 × 3 × 20	3.04
	20	1 × 1 × 1 × 20	3.14
	10	1 × 1 × 1 × 10	4.45
	5	1 × 1 × 1 × 5	8.68
Endocarp	540	3 × 3 × 3 × 20	5.25
	60	1 × 1 × 3 × 20	5.26
	20	1 × 1 × 1 × 20	5.78
	10	1 × 1 × 1 × 10	8.18
	5	1 × 1 × 1 × 5	11.58

[1] Sample means are 9.23 Newton, mesocarp and 1.90 Newton, endocarp. Calculations are based on data given in Table 2

where MS = mean square, 9 = number of punches per section, and 27 = number of punches per cucumber. Thus, for the variance for mean firmness of mesocarp tissue:

$$V_{\bar{x}i\cdots} = \frac{1.527}{30} + \frac{0.155}{(30)(3)} + \frac{0.00516}{(30)(3)(3)(3)} = 0.0526$$

Variances of sample means for endocarp tissue may be similarly determined.

Various combinations of c, s, i, and p were applied to the variance equation (Table 3). It is clear that the most efficient way to reduce $V_{\bar{x}i\cdots}$ is to increase the number of cucumbers, as was expected since cucumbers accounted for 68% of the variation in mesocarp tissue firmness (Table 2). Coefficients of variation for mesocarp and endocarp were less than 6% when a single punch (from the middle section) was made on 20 cucumbers. It should be emphasized that these data were determined from a relatively homogeneous lot of cucumbers. Larger variances might be expected with cucumbers which vary as to cultivar, storage time, conditions after harvest, and other factors. In fact, we have obtained larger variations among other lots of cucumbers. Thus, we suggest that 20 cucumbers, punched once each in the mesocarp (location 2) and endocarp of a slice from the center section of each cucumber would represent a favorable compromise between accuracy and speed when whole cucumbers are evaluated for firmness by the punch test. Less accuracy should be expected when the cucumbers are sliced and the slices randomly mixed before sampling, depending upon the number of cucumbers represented by the 20 slices. Jones *et al.* (1954) tested the firmness of whole, salt-stock cucumbers with a USDA Fruit Pressure Tester (Magness-Taylor) equipped with a 5/16 in. tip. They determined the means of single punctures made at the center of each of 20 cucumbers, which is consistent with the sampling procedure that we suggested above for the puncture test for cucumber slices.

Confirmation of the Punch and Die Test by Sensory Analysis

Means of sensory panel firmness ratings for fermented cucumbers were highly correlated with the means of penetration force for mesocarp tissue (r = 0.88, Fig. 6). Thus, the punch test apparently is a reasonably good predictor of sensory firmness.

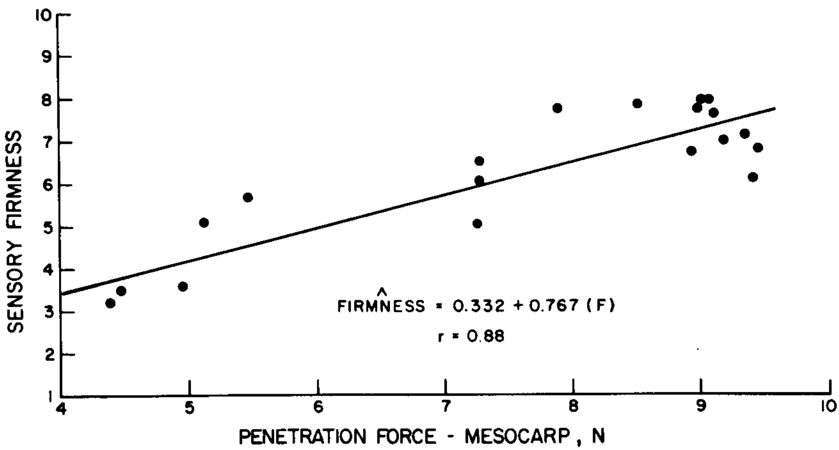

FIG. 7. RELATIONSHIP BETWEEN PENETRATION FORCE OF MESOCARP TISSUE AND SENSORY FIRMNESS OF CUCUMBER SLICES

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REFERENCES

BELL, T. A., ETCHELLS, J. L. and JONES, I. D. 1955. A method for testing cucumber salt-stock brine for softening activity. U. S. Dept. of Agr., Agr. Res. Serv. ARS-72-5.

BOURNE, M. C. 1975. Method for obtaining compression and shear coefficients of foods using cylindrical punches. J. Texture Studies *5,* 459-469.

BREENE, W. M., DAVIS, D. W. and CHOU, H.-E. 1972. Texture profile analysis of cucumbers. J. Food Sci. *37,* 113-117.

BREENE, W. M., JEON, I. J. and BERNARD, S. N. 1974. Observations on texture measurements of raw cucumbers with the fruit pressure tester. J. Texture Studies *5,* 317-327.

FLEMING, H. P., THOMPSON, R. L., BELL, T. A. and HONTZ, L. H. 1978. Controlled fermentation of sliced cucumbers. J. Food Sci. *43,* 888-891.

GOFFINET, M. C. 1977. Some anatomical considerations in the study of cucumber fruit texture. J. Amer. Soc. Hort. Sci. *102,* 474-478.

HUDSON, J. M. and BUESCHER, R. W. 1980. Prevention of soft center development in large whole cucumber pickles by calcium. J. Food Sci. *45,* 1450-1451.

JEON, I. J., BREENE, W. M., and MUNSON, S. T. 1973. Texture of cucumbers: correlation of instrumental and sensory measurements. J. Food Sci. *38,* 334-337.

JONES, I. D., ETCHELLS, J. L. and MONROE, R. J. 1954. Varietal differences in cucumbers for pickling. Food Technol. *8,* 415-418.

JONES, I. D., ETCHELLS, J. L., VELDHUIS, M. K. and VEERHOFF, O. 1941. Pasteurization of genuine dill pickles. Fruit Prods. J. *20,* 304-305, 316, 325.

MAGNESS, F. R. and TAYLOR, G. F. 1925. An improved type of pressure tester for determination of fruit maturity. U. S. Dept. of Agr., Circ. 350.

MARSHALL, D. E., HOOPER, A. W., BAKER, L. R. and HELDMAN, D. R. 1975. A method for measurement of carpel strength in cucumbers. Trans. ASAE *18,* 752-754.

MCFEETERS, R. F., BELL, T. A. and FLEMING, H. P. 1980. An endopolygalacturonase in cucumber fruit. J. Food Biochem. *4,* 1-16.

MILLER, J. C., JR. and MOREY, P. R. 1977. Anatomical differences associated with inherent carpel separation along ventral sutures in pickling cucumber. J. Amer. Soc. Hort. Sci. *102,* 410-413.

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,* 71-77.

SNEED, F. D. and BOWERS, J. L. 1970. Using characters in fresh cucumbers to predict quality of the brined stock. Arkansas Farm Research, January-February, p. 8.

SU, C. S. and HUMPHRIES, E. G. 1972. Rupture properties of cucumber skin. Pickle Pak Sci. *2,* 1-10.

THOMPSON, R. L., FLEMING, H. P. and MONROE, R. J. 1979. Effects of storage conditions on firmness of brined cucumbers. J. Food Sci. *44,* 843-846.