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A COMPARISON OF THE TEXTURAL PROPERTIES OF SEVERAL SPAGHETTI VARIETIES AND SOME OBSERVATIONS ON THE ACCURACY OF AN OBJECTIVE TECHNIQUE

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Peter W. Voisey[1] and Elizabeth Larmond[2]

SUMMARY

Differences in firmness and gumminess between spaghetti varieties were measured by sensory analysis. Differences between some varieties were significant. Objective tests using multiblade shear and multiblade shear-compression test cells were sensitive to differences in spaghetti texture and showed that more varieties were significantly different in firmness than the sensory tests. Sensory and objective results were related, but the textural range tested was too narrow to prove this conclusively. Gumminess appeared to be inversely related to firmness.

It appears that to be interchangeable the texture test cells must be made very precisely. The apparent differences between cells is affected by the variety of spaghetti used. The multiblade shear-compression test cell requires careful interpretation of the results since the rupture of the sample is indicated by different characteristics of the force deformation curve depending on variety.

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1.0 INTRODUCTION

Previous work (14, 30, 31) indicated that textural properties of cooked spaghetti could be evaluated and differences between varieties detected by objective and sensory techniques. The objective technique was to shear 10 sticks by 10 shearing blades, cutting the sticks at 100 points. The consumer appeared to prefer spaghetti which received low scores for gumminess, adhesiveness and starchiness and higher scores for firmness (14). Laboratory panel ratings of firmness and gumminess were sufficient to predict consumer acceptability.

The purpose of the work reported here was to extend the previous experiments to additional spaghetti varieties and investigate some performance aspects of the shearing test. A previous report (30) reviews other researchers' work on spaghetti texture and describes the development of the methods used here.

2.0 SOURCE OF TEST MATERIAL

Seventeen spaghetti varieties were supplied by the Grain Research Laboratory, Winnipeg (GRL). Eight (No. 1 to 8, Table 1) were the same as tested in 1971 after storage under proper conditions for a year. These were made from different wheat varieties and processed under commercial conditions in Canada, U.S.A. and Italy. Nine additional varieties (20 to 28, Table 1) were made from different wheat varieties under experimental conditions by the G.R.L. and commercial conditions in Canada.

3.0 EXAMINATION OF OBJECTIVE TEST METHOD

The original multiblade shearing cell was made to fit an Instron Testing Machine (Model TM-M Instron Canada Ltd., Burlington, Ontario). The design was revised and a second cell made for the Ottawa Texture Measuring System (24).

The cell (Fig. 1) consists of an upper component driven by the test machine crosshead and a fixed component attached to the base. The upper component is a plate holding 10 equally spaced parallel shearing blades. Two types of bottom components can be used: a) a plate with 10 parallel slots matching the 10 blades, so that the blades shear the spaghetti sticks into the slots - called the multiblade shear cell (30); b) a flat plate so that the blades compressed the sticks onto the plate and then sheared or forced them apart - called the multiblade shear-compression cell (30). Preliminary tests on the multiblade shear compression cell (30) indicated that it operated satisfactorily, but it was assumed that the final clearance between the blades and plate during operation would be critical. It was, therefore, discarded at that time.

The only difference between the "old cell" previously used and the "new cell" was the width along the axis of the shearing blades. The sticks of spaghetti were closer together in the new cell (Fig. 1). Theoretically, this should not affect its performance.

The readings obtained from the old and new cells were compared using two spaghetti varieties (no. 1 and 10 from 1971 tests). Ten samples of each were tested in each multiblade shear cell using a shearing rate of 5 cm/min in the Instron Testing Machine. Each sample consisted of 10 sticks cooked for the optimum time (30). The blade thickness and width of slot was measured for each cell. The results (Table 2) indicate that the small difference in blade thickness (1.5%) and width of slots (2.26%) introduced a large difference in clearance between the blades and slots (8.3%). This clearance, theoretically, has a marked effect on the shearing stresses imposed on the spaghetti. This is reflected in the shear force

where differences of 14.0 and 8.1% between the cells were recorded for the two varieties tested. The smaller clearance created higher stresses in the spaghetti and produced lower shearing forces.

The small dimensional differences in blade and slot widths are within the practical tolerances that would have to be allowed for economic manufacture of the cells. Thus, it would appear costly to manufacture interchangeable cells. Another aspect that was not investigated was the effect of alignment between the blades and slots which, theoretically, also affects the shearing stresses and thus shear force. The alignment was carefully done by visual observation so that the blades were centralized relative to the slots, but measurements were not made to achieve this. Penetration of the blades into the slots without a sample did not generate any force, i.e. the blades did not touch the slots. It was also observed that shearing occurred before the blades entered the slots.

These results indicated that the shear compression cell should be re-evaluated to replace the shear cell. The shear compression cell has the advantage that it is not necessary to control the clearances between the blades and slots. Theoretically, two criterion with this cell are the blade thickness and the clearance and parallelism between the blades and flat bottom plate. The minimum clearance between the plate and blades must have some effect since as the blades approached the plate, material was trapped under the blades and compression continued throughout the blade movement. The effect of minimum clearance between the plate and blades and blade thickness on the maximum force recorded in the test (the characteristic used as a textural index) was, therefore, investigated.

3.1 Effect of clearance between blades and plate

The blades of the shear compression cell were set exactly parallel to the plate. The crosshead control mechanism was adjusted to stop the blades 0.1524 mm from the plate. One sample of each of 12 varieties, each consisting of 10 sticks cooked for the optimum time, was then tested at a shearing rate of 5.0 cm/min. This was repeated using clearances of 0.254, 0.508 and 0.762 mm. These clearances were checked throughout the test. A 30 hz recorder was used to eliminate the possibility of attenuating the force signal by recorder response. A high chart speed (10 mm/sec) was also used so that details on the records were clearly visible.

Typical force records (Fig. 2) indicate that in the majority of the varieties the force increases almost linearly up to a maximum (Fig. 2A). However, as the clearance was decreased, two varieties (No. 4 and 5) exhibited a different characteristic. The peak became rounded at a clearance of 0.508 mm, and then a second peak started to develop as the clearance was further reduced. This was interpreted as follows:

1. A linear relationship up to the maximum indicates that compression continues throughout the deformation of the sticks, i.e. the maximum force may be more related to the compressive behavior (i.e. firmness) than to the shearing properties. This type of result was called a compressive peak (or maximum force).
2. A rounded peak with a secondary peak indicates that the sticks are compressed until they are forced apart, and some of the material trapped under the blades is then further compressed. Thus, the first peak may be indicative of the force required to tear the sticks apart, i.e. to cause rupture probably by forcing the stick apart in an axial direction which may be related to its tensile properties. The secondary peak is related to the compressibility of the material. The two peaks, thus, do not indicate the same property. This type of result was called a rupture peak.

If the maximum force is to be used as an index, then it must be known what type of behavior is causing the maximum reading, rupturing or compression. The maximum force or peak is a convenient parameter to record (23) either from strip-chart records or a peak detection system. The maximum force was markedly affected by clearance and increased consistently as the clearance decreased (Table 3). Definite double peaks were only recorded for two varieties at the two smallest clearances tested. Thus, the behavior was affected by clearance and variety. The relationship between clearance and maximum force was approximately linear (Fig. 3).

3.2 Effect of blade thickness and clearance between blades and plate

Single blades and a special holder were made so that blades of various thickness (0.254, 0.635, 0.8128, 1.016 and 1.5748 mm) could be tested. Five samples of 4 varieties each consisting of 10 sticks were then tested using a clearance between the blade and plate of 0.1524 mm. Optimum cooking times and a shearing rate of 2.5 cm/min were used. This was then repeated at clearances of 0.254, 0.508 and 0.762 mm. The characteristic of the force - deformation curve was noted in each case and the maximum force noted, but if a double peak occurred, the force at the first peak was noted, i.e. the rupture force.

The results (Table 4) indicate that as the blade thickness is increased and the blade clearance reduced, the curve characteristic changes from predominantly a single peak (compression) to predominantly a double peak (rupture). At the larger clearances for all blade thicknesses the curves are either a single rounded peak (Fig. 4A) indicating that rupture has occurred before the blade completes its travel, or single sharp peak (Fig. 4B) indicating that compression continued throughout the blade's travel. As the blade thickness is increased (Fig. 5), or the clearance is reduced (Fig. 6), there is a distinct change in the characteristic curve. The thickness and clearance at which these changes take place is not the same for each variety. This can be attributed to a) different properties of the varieties and b) the differences in stick diameter which affects the degree of compression.

If the different curve characteristics are recognized and only the maximum force noted for the compressive peaks and the first peak noted for rupture peaks, it appeared that the effect of blade clearance is small (Table 4). There was a general tendency for the force to increase as the clearance decreased with all blade thicknesses except one case (Fig. 7). There was an approximately linear relationship between blade thickness and force (Fig. 8) at each of the blade clearances tested.

Two varieties (4 and 5) produced the same rupturing characteristic with the multiblade shear compression cell when the spaghetti was both over and under cooked related to the optimum cooking time. The rupture shear force decreased as cooking time was increased (Fig. 9). This agrees with previous results from the multiblade shear cell (30, 31).

To further study the characteristic behavior, the multiblade shear compression cell was operated with the Instron load controls set to automatically stop the crosshead at 20 kg. Thus, the shearing blades continued movement until they touched the bottom plate and applied a force of 20 kg. This was far in excess of the forces recorded with the minimum clearance normally used (0.1524 mm). The recorder chart was run at high speed (100 cm/min) so that the characteristic curves were shown clearly. The two varieties (4 and 5) exhibiting the rupturing type peak maintained this characteristic (Fig. 10A and B). Two varieties (27 and 28) which normally exhibited a compression type peak were tested. The expanded time scale showed that there was a distinct change in slope during what had been assummed to be only a compression phase (Fig. 10C & D). The change in slope was presumed to be caused by the sticks rupturing in an axial direction. The rate of increase of force then changes because a) the material has ruptured and b) the quantity of spaghetti trapped under the blades is reduced. When the blade deformation stopped, the material remaining squashed between the blades and plate started to relax, as indicated by the decrease in force with time. The blades and plate were glued together by the sample.

3.3 Discussion and Conclusions

It appears that the behavior of the spaghetti in the shear compression cell is affected by blade clearance and blade thickness. Since blade clearance has an effect, the diameter of the sticks may also affect the result since the amount of compression of the material depends also on the original diameter of the stick. The change of characteristic from a compression to a rupture type peak may be a useful indicator of spaghetti texture since it must be related in some way to its toughness. The shape of the single peaks (rounded or sharp) may also be a useful index. To consistently measure the same rupturing characteristic from the multiblade shear compression cell, only a strip chart recording can be used to determine the rounded peak height, or point at which the force deformation curve changes slope. The latter involves the use of high chart speeds, and is costly. The maximum force indicated in the multi-blade shear test is, in theory, related to the compressibility, i.e. firmness of the product, and may not predict its rupturing behavior which relates to the chewiness and cohesiveness of the material. The action of the cell, in theory, simulates the consumers' biting action, so the force deformation characteristic should predict consumer reaction.

A test on all available varieties from 1971 (Table 1A) and 1972 (Table 1) showed that all the 1971 samples except one (12, Table 1A) exhibited a rupture type peak. All the 1972 varieties and number 12 from 1971 exhibited a compression type peak. This may indicate that the characteristic failure of spaghetti changes during storage. The mode of failure may have a significant effect on consumer mouth feel. In the rupture type peak a sudden reduction in biting force would be sensed, whereas in a compression type a change in rate of force increase would be apparent. Since it is well known that the human is sensitive to such effects, it seems reasonable that rupture characteristics would affect consumer reaction. In the samples tested here this might result in the rupture type being considered soft and the compression firm. Extensive sensory testing would be required to prove this. A comparison of measured failure characteristics, and sensory and objective readings did not indicate any relationship, probably because the sensory range of firmness was narrow.

The shear compression technique can only be used if clearance and blade thickness are carefully controlled. Blade thickness does not present a problem since this can be easily controlled within $\pm$ 0.025 mm which should introduce only small changes in the results (about $\pm$ 10 g, Fig. 8). Controlling blade clearance accurately requires an expensive testing machine where crosshead travel is precisely controlled. For example, at 2.5 cm/min the Instron crosshead was found to shift its stopping point 0.076 to 0.102 mm during 10 test cycles. To observe the characteristic behavior of the force-deformation curve high chart speeds must be used in order to see if a compression or rupture type peak occurs. For quality control tests this is undesirable since electronic peak detection is economical and can provide a single number related to texture. It was, therefore, concluded that the multiblade shear compression cell was not suitable for comparing the textural properties of cooked spaghetti in quality control applications, but may provide a useful research tool.

4.0 OBJECTIVE COMPARISON OF VARIETIES

4.1 Sample preparation

Ten sticks of spaghetti were placed flat in a perforated metal tray and immersed in a hot water bath maintained at 98 $\pm$ 1^{o}C and cooked for the optimum time. Optimum cooking times weredetermined in preliminary tests using the Braibanti squeeze technique (30), i.e. it was cooked "to just eliminate the hard central core" (see Irvine, G.N. 1964. Durum wheat and paste products. In Wheat Chemistry and Technology Ed. I Hylynka. Amer. Assoc. Cereal Chem., St. Paul, Minnesota). Diameter of the sticks was measured before and after cooking. When cooked, the samples were transferred immediately to the texture test cell and tested.

4.2 Test conditions

All samples were tested in the Instron using a shearing rate of 2.5 cm/min, and the shearing force was recorded on a strip-chart. The shear compression cell was operated so that the crosshead was stopped when the blades were 0.1524 mm (0.006 in) from the plate. This clearance was carefully monitored and maintained throughout the test.

4.3 Tests executed

Ten replicates of each variety were tested in both the old and new shear and shear-compression cells. From the multiblade shear cell data, the shear stress was calculated:

$$\text{Stress} = \frac{\text{load}}{\text{area}}$$

Area of 1 stick $= \frac{\pi d^2}{4}$, where d = diameter of stick after cooking.

But 100 sticks were sheared and failure generally occurred on one side of the blade, i.e. total area sheared $= 100 \frac{\pi d^2}{4}$

$$= 25\,\pi d^2$$

i.e. Stress $= \frac{W}{25\pi d^2}$, where W = force.

The maximum force was noted in all tests using the multiblade shear compression cell.

4.4 Results

It was observed in the multiblade shear cell that sample rupture occurred when the shearing blades were about level with the top of the shearing slots. Thus, the blades did not enter the slots before the critical point where the force maximized. Thus, friction between the blades and slot could not affect the measurement.

4.4.1 Cooking times and sample diameter

The optimum cooking time for the 17 varieties ranged from (10 to 19 min), but a number of the varieties had similar cooking times (Table 5). The diameter of the sticks changed by 56 to 92% averaging a 75% change during cooking (Table 5). The diameters ranged from 1.3 to 1.9 mm before cooking and 2.5 to 3.1 mm after. There was a degree of relationship between diameter before and after cooking (Fig. 11), but insufficient for prediction purposes.

4.4.2 Effect of shearing rate on the multiblade shear-compression cell results

Previous work (30) showed that the shearing rate had a marked effect on the shearing force in the multiblade shear cell. A comparison of results for 5 varieties obtained at shearing rates of 2.5 and 3.0 cm/min showed that this was also the case with the multiblade shear compression cell. A change of 0.5 cm/min in shearing rate introduced differences of 29 to 40.5% in the results (Table 6). Similarly differences of 9.8 to 20.4% were observed in results from the multiblade shear cell (Table 7). It thus appears that at these slow shearing rates where the effect of shearing rate is greatest (30), the effects are larger for the shear compression cell than the shear cell. This is a further point disqualifying the shear-compression cell for routine use.

4.4.3. Comparison of new and old cells

The readings obtained in the old and new multiblade shear and multiblade shear compression cells were generally different, but the differences covered a wide range and depended on the variety tested (Table 8, 9 and 10). The differences were not consistent and depended on variety ranging from 0.87 to 28.75% for the multiblade shear cell and 0.56 to 24.04 for the multiblade shear compression cell. The amount of difference was about the same for the shear and shear compression cells in only 7 of the 17 varieties. The differences between cells cannot be explained only on the basis of geometrical differences between cells. The magnitude of the differences cannot be attributed to the differences in cell dimensions particularly since there appears to be a varietal effect.

4.4.4 Comparison of varieties

The objective readings are summarized in Table 8 (shear force), Table 9 (shear stress) and Table 10 (maximum shear compression force). An analysis of variance of the data for the 1971 varieties, the 1972 varieties and 1971 and 1972 varieties pooled indicated that there were significant differences ($P > 0.05$) among varieties within those groups (Table 12). The differences among varieties appeared to be greater for the shear force among the 1971 samples than for the 1972 samples. This appears reasonable since the 1972 varieties were processed by only two manufacturers (G.R.L and Commercial), whereas the 1971 varieties came from a number of sources. Tukey's test of least significant difference showed that there were differences between several varieties indicated by all the objective readings.

The variation of all readings within varieties was at an acceptably low level (total range 2.39 to 13.03%). It thus appears that readings are repeatable within both types of test cells. The range of readings for all 17 varieties was relatively large and was about the same for each cell type (40 to 54%). The range of shear stress was slightly lower than shear force indicating the same effect of stick size as previously noted (30).

4.4.5 Relationship between multiblade shear force and maximum shear compression force and between old and new cells

The shear force and maximum shear compression force were not strongly related. This is shown by the scatter in the data (Fig. 12). Correlation among these readings was indicated, but coefficients only ranged from 0.50 to 0.79 (Table 11). This supports the preliminary tests which indicated that the shear force and maximum compression shear force are not measurements of the same spaghetti property. The relationship between the old and new shear cell readings was not as close as would be expected ($r = 0.56$, Table 11), whereas the old and new shear compression cell readings appeared to be more strongly related ($r = 0.80$ Table 11).

There was considerable differences in ranking of varieties within test cell type when the old and new cells were compared, particularly where there were no significant differences between varieties (Table 13). The softest variety (8), however, was ranked lowest in each case, and there was a degree of agreement among ranks for the firmest varieties.

5.0 SENSORY COMPARISON OF VARIETIES

5.1 Sample Preparation

The spaghetti was cooked by holding 9 cm lengths, making up a 50 g sample, in 500 ml of 99°C water containing 1% salt in a 600 ml beaker for the optimum cooking time. The beaker was held in a covered laboratory hot water bath kept at 100°C. The time required for each variety was determined in preliminary tests. After cooking, the sample was drained and immediately plunged into 2 l of 19 - 21°C water for 1 min. The spaghetti was presented cold to the judges for evaluation.

5.2 Test executed

Several preliminary tests were held to train the eight judges. Previous work indicated that firmness and gumminess ratings could be used to predict consumer acceptability. Each of these characteristics was rated by eight trained judges using descriptive scales (Table 14).

Definitions of the textural properties were based on those given by Szczesniak et. al. (1963) as follows:

Firmness is judged organoleptically as the force required to penetrate a substance with the molar teeth.

Gumminess is described as a denseness that persists throughout mastication.

The nine varieties of spaghetti supplied by the Grain Research Laboratory in 1972 (Table 1) consisted of 6 varieties of wheat that had been processed experimentally by the G.R.L. (20, 21, 22, 23, 27 and 28) and three varieties that had been processed under commercial conditions (24, 25 and 26).

The testing was done in two phases. The six experimentally processed varieties were compared (1). The three varieties that had been processed under both experimental and commercial conditions were also compared (2) (20, 21, 22, 24, 25 and 26). On each day of testing 6 varieties were evaluated. Each phase was repeated seven times.

5.3 Results

The results are summarized in Table 15. Analysis of variance indicated significant differences ($P > 0.05$) among varieties for firmness and gumminess. Variety 21 was significantly firmer than varieties 24 and 28. Varieties 22 and 28 were significantly more gummy than varieties 26 and 24. Variety 24 was less gummy than varieties 21, 22 and 28.

The mean firmness ratings were near the mid-point of the scale for all varieties (5.19 - 4.45). Large differences in firmness were not expected since all samples were cooked until the hard central core was just eliminated. Gumminess scores covered a wider range of the scale (2.31 - 4.97).

Commercial processing resulted in considerably lower gumminess rating for each of the three varieties processed by both methods (2.31 vs 3.66; 2.96 vs 4.66; 3.69 vs 5.21).

The optimum cooking times for the sensory tests were not exactly the same as those determined for the objective tests. The differences ranged from 0 to 1.5 min (Table 5). These can be explained by the different techniques used to prepare the samples. This points out that control of the cooking process is critical.

6.0 COMPARISON OF SENSORY AND OBJECTIVE RESULTS

The sensory and objective readings for 9 varieties are summarized in Table 16. Correlation coefficients among these readings are given in Table 17. Significant correlations were found between firmness and both the old ($r = 0.69$) and the new ($r = 0.45$) shear compression cells and the new shear cell ($r = 0.53$), but not the old ($r = 0.20$). Shear stress was not related to firmness. Gumminess appeared to be related to shear stress, shear force in one cell and shear compression force in one cell. However, these relationships must be viewed from the fact that the sensory readings of firmness only ranged 14%, whereas gumminess ranged 56% and the instrument readings 36 to 54% (Table 16). Also both firmness and gumminess only ranged over the mid portion of the sensory rating scales. Plots of the data indicate the scatter in the relationships between firmness (Figure 13), gumminess (Figure 14) and the instrument readings. An interesting point is that gumminess tends to decrease as the instrumental indication of firmness increases.

A comparison of the rank of each variety according to sensory and instrument readings (Table 18) shows that where there are significant differences in firmness, there is a general agreement between the taste panel and objective tests, i.e. both rate the softest and firmest varieties at about the same level. Again this comparison shows that gumminess and firmness tend to be inversely related.

7.0 COMPARISON OF 1971 AND 1972 OBJECTIVE READINGS

For varieties 1 to 8 readings were taken in 1971 and 1972 about 12 months apart so a comparison of the results could be made.

The cooking time for 4 of the varieties was unchanged, but in the remaining 4 it had increased by 5.6 to 33.3% (Table 19). The diameter of the uncooked sticks decreased in all except one case by 5.6 to 11.1%, i.e. the spaghetti had continued drying in storage and had shrunk. The diameter after cooking in 1972 decreased in several varieties compared to 1971 but increased in others. The change in diameter was generally greater in 1972 than 1971. This would indicate that the drier spaghetti cooked for a longer time absorbed more water.

The spaghetti was much firmer after one year's storage as indicated by shear force and stress readings in the old multiblade shear cell (Table 20). This was confirmed by brief sensory tests (before the objective results were known) when the panelists remarked that the 1971 samples tended to be firmer.

8.0 COLOUR

Colour of the cooked spaghetti (1972 varieties) was measured on the Agtron Reflectance Spectrophotometer, Model M-400-A. Since the presence of a brownish tinge in cooked spaghetti is undesirable and since red and beige products are usually investigated for redness, the spaghetti was investigated for red reflectance. Higher reading indicates greater degree of redness. The spaghetti was prepared by blending 50 g spaghetti with 25 ml water in a Waring Blendor at medium speed for 1 minute. Duplicate readings were taken on each sample of spaghetti.

Colour readings on red mode
(setting 0 = 63, 100 = 78)

Sample	Reading
20	37
21	63
22	63
23	49
24	41
25	47
26	46
27	55
28	62

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Table 1. Spaghetti varieties tested in 1972.

Code	Year manufactured or purchased[1]	Method of manufacture[2]	Country of manufacturer
1	1971	Commercial A	Canada
2	1971	Commercial A	Canada
3	1971	Commercial A	Canada
4	1971	Commercial B	Italy
5	1971	Commercial B	Italy
6	1971	Commercial B	USA
7	1971	Commercial B	Italy
8	1971	Commercial B	Italy
20	1972	Experimental C	Canada
21	1972	Experimental C	Canada
22	1972	Experimental C	Canada
23	1972	Experimental C	Canada
24	1972	Commercial D	Canada
25	1972	Commercial D	Canada
26	1972	Commercial D	Canada
27	1972	Experimental C	Canada
28	1972	Experimental C	Canada

[1] 1971 samples stored by Wheat Board till 1972.

[2] A. all processed by one manufacturer; B. imported; C. processed by Grain Research Laboratories; D. all processed by one manufacturer from experimental wheat samples.

Table 1. Spaghetti samples tested.

Code	Source*	Purchase Date 1971	Remarks
1	GRB	August	Processed from variety Pellissier.
2	GRB	August	Regular domestic spaghetti.
3	GRB	August	Processed from variety Hercules.
4.	GRB	August	Processed in Italy.
5	GRB	August	Processed in Italy.
6	GRB	August	Processed in U.S.A.
7	GRB	August	Processed in Italy.
8	GRB	August	Processed in Italy.
9		-	Experimental material processed in Canada.
10		-	Institutional pack processed in Canada.
11	D-A1	May	Vitamins added.
12	D-A2	August	No vitamins.
13	D-B1	May	Vitamins added.
14	D-B2	August	No vitamins.
15	D-C1	May	
16	D-C2	August	
17	D-E	August	
18	D-F	May	
19	D-G	May	

*GRB = Grain Research Board.

D = Domestic pack from retail store - No. indicates brand name and first and second purchase.

Table 2. Comparison of shearing force for two multiblade shearing cells.

Variety	Test Cell		Old	New	Difference[a]	% Difference[b]
	Blade thickness	mm	1.651	1.6764	-0.0254	-1.54
	Slot width	mm	2.5654	2.5146	0.0508	2.26
	Clearance	mm	0.9144	0.8382	0.0762	8.33
1	Average shear force	g[c]	5316	4582	734	14.0
	C.V.	%	8.48	5.79		
10	Average shear force	g[c]	4144	3809	335	8.1
	C.V.	%	3.11	2.51		

a. Old - New

b. $\frac{\text{Old - New}}{\text{Old}} \times 100\%$

c. for 10 samples

Table 3. Effect of clearance between blades and plate on shear force.

Variety	Shear force kg*			
Clearance mm	0.1524	0.254	0.508	0.762
1	19.3	16.3	12.3	10.5
2	16.3	17.0	13.0	11.5
3	19.4	14.5	12.0	11.3
4	19.0*	13.5*	17.0	17.0
5	20.4*	16.0*	15.5	14.5
6	21.3	17.3	16.3	11.8
7	21.0	18.8	17.5	14.0
8	13.3	12.3	11.0	8.3
20	17.0	16.0	14.5	11.5
21	24.3	19.0	15.8	12.0
22	20.5	19.5	15.0	11.0
23	21.5	16.5	15.5	12.5
Mean	16.7	14.1	12.5	10.4

*These results showed a definite double peak

Table 4. Shear force using using single blades of 5 thicknesses at four clearances and noting maximum or rupture force depending on the force deformation characteristic.

Variety	Blade Clearance (mm)	Force (g)[a]				
		Blade Thickness (mm)				
		1.5748	1.016	0.8128	0.635	0.254
1	0.1524	653*	697*	591**	648*	425
4		958*	820*	599**	614*	396
5		906*	890*	687**	637*	458
23		848*	782*	592**	638*	419
Mean:		841	797	617	634	425
1	0.254	721*	579*	443**	456*	350
4		1008*	855**	614**	605	446
5		922*	743*	613**	692	490
23		826*	768*	624*	645*	484
Mean:		869	736	574	600	443
1	0.508	728*	500*	399	421	360
4		969**	781	583	595	460
5		925*	843	620	646	476
23		1061	774	620	562	395
Mean:		921	725	556	556	423
1	0.762	702	564	415	431	318
4		967	662	593	620	459
5		1082	816	600	662	455
23		825	691	588	591	393
Mean:		894	683	549	576	406

(a) Means of 5 samples (10 sticks/sample). Maximum or rupture force in g.

*Indicates a second higher peak after rupture in one or more of the samples.

**Indicates a second lower peak after rupture in one or more the samples.

Table 5. Optimum cooking times and diameter of sticks before and after cooking.

Variety	Diameter of stick: Before cooking (mm)	After cooking (mm)	Percent change* (%)	Optimum Cooking Time (min): Objective	Sensory	Difference
1	1.6	2.5	56	11		
2	1.6	2.8	75	11		
3	1.7	2.8	65	12		
4	1.8	3.1	72	19		
5	1.9	3.1	72	16		
6	1.5	2.5	67	12		
7	1.7	3.0	76	15		
8	1.3	2.5	92	11		
20	1.6	3.0	88	14	14	0
21	1.6	3.0	88	12	13	+1.0
22	1.7	3.0	76	13	12.5	-0.5
23	1.6	3.0	88	14	13.5	-0.5
24	1.7	2.7	59	10	11.5	+1.5
25	1.6	2.8	75	11	11.5	+0.5
26	1.5	2.8	87	11	12.5	+1.5
27	1.7	3.0	76	12	13.0	+1.0
28	1.8	2.8	56	12	12.0	0
Mean	1.6	2.8	75	12		
C.V. %	8.4	7.2	15.3	17.9		
Minimum	1.3	2.5	56	10		
Maximum	1.9	3.1	92	19		
Range %**	32	19	40	47		

$^{*}\frac{\text{After - Before}}{\text{Before}} \times 100\%$

$^{**}\frac{\text{Max - Min}}{\text{Max}} \times 100\%$

Table 6. Effect of shearing rate on shear force in the new multiblade shear compression cell.

Variety	Shear rate cm/min	Shear force[a] 3.0	Shear force[a] 2.5	Shear force[a] Difference[b]	Coefficient of variation 3.0	Coefficient of variation 2.5
		kg	kg	%	%	%
24		27.4	16.3	40.5	12.1	5.2
25		23.4	15.1	35.5	14.6	3.9
26		26.2	15.6	40.5	3.8	5.6
27		18.8	13.3	29.3	3.3	4.4
28		21.5	13.2	38.6	8.1	4.6

[a]Mean of 10 samples

[b] $\frac{3.0 - 2.5}{3.0} \times 100\%$

Table 7. Effect of shearing rate on shear force in the new multiblade shear cell.

Variety		Shear Force[a]			Coefficient of variation	
	Shear rate cm/min	3.0	2.5	Difference[b]	3.0	2.5
		kg	kg	%	%	%
24		6.4	5.5	14.1	8.3	4.1
25		5.6	4.7	16.1	5.1	3.9
26		6.1	5.5	9.8	3.6	6.8
27		4.9	3.9	20.4	7.7	6.2
28		5.0	4.5	10.0	7.6	6.4

[a]Mean of 10 samples

[b]$\frac{3.0 - 2.5}{3.0} \times 100\%$

Table 8. Summary of results for old and new multiblade shear cells - Average shear force for 10 replicates of each variety.

Variety	Shear force					Coefficient of variation	
Cell:	Old		New		Difference[a]	Old	New
	kg		kg		%	%	%
1	4.60	g	5.42	bcd	15	4.1	4.1
2	4.96	fg	5.01	def	1	2.9	5.3
3	5.68	de	4.96	efg	-14	7.0	4.6
4	5.73	d	5.80	b	1	5.9	6.2
5	6.54	b	6.36	a	- 3	6.0	3.7
6	4.04	h	5.67	bc	29	2.4	3.9
7	5.51	de	6.32	g	13	6.1	3.6
8	3.25	i	3.85	h	16	3.9	3.8
20	5.29	def	5.24	cde	- 1	4.5	3.0
21	6.31	b	5.66	bc	-11	2.6	9.9
22	5.68	de	5.73	b	1	6.4	5.9
23	5.54	de	5.69	bc	3	3.6	4.9
24	6.23	bc	5.49	bc	-13	5.4	4.1
25	5.75	cd	4.68	fg	-23	8.0	3.9
26	7.07	a	5.52	bc	-28	6.7	6.8
27	4.67	g	3.94	h	-19	4.4	6.2
28	5.24	ef	4.52	g	-16	7.5	6.4
Mean	5.42		5.29		12	5.2	5.1
C.V. %	17.20		13.59		77	33.9	33.6
Minimum	3.25		3.85		0.87	2.39	2.98
Maximum	7.07		6.36		28.75	8.00	9.93
Range %[b]	54		39		97	70	70

[a] $\frac{\text{New} - \text{Old}}{\text{New}} \times 100\%$; [b] $\frac{\text{Maximum} - \text{Minimum}}{\text{Maximum}} \times 100\%$

Different letters indicate real differences between varieties.

Table 9. Summary of results for old and new multiblade shear cells - Average shear stress for 10 replicates of each variety.

Variety Cell:	Old kg/mm^2	New kg/mm^2	Difference[a] %
1	9.37	11.03	15
2	8.06	8.13	1
3	9.22	8.05	-15
4	7.59	7.86	3
5	8.66	8.43	- 3
6	8.23	11.54	29
7	7.80	8.94	13
8	6.62	7.84	16
20	7.48	7.41	- 1
21	8.93	8.00	-12
22	8.04	8.11	1
23	7.84	8.04	3
24	10.88	9.60	-13
25	9.34	7.60	-23
26	11.48	8.97	-28
27	6.60	5.57	-18
28	8.51	7.34	-16
Mean	8.51	8.38	-12.2
C.V. %	15.3	16.5	75.3
Minimum	6.60	7.34	0.86
Maximum	11.48	11.54	28.68
Range %	42	36	97

[a] $\frac{\text{New} - \text{Old}}{\text{New}} \times 100\%$; [b] $\frac{\text{Maximum} - \text{Minimum}}{\text{Maximum}} \times 100\%$

Different letters indicate real differences between varieties.

Table 10. Summary of results for old and new multiblade shear compression cells - Average maximum force for 10 replicates of each variety.

Variety	Maximum force			Coefficient of variation	
Cell:	Old	New	Difference[a]	Old	New
	kg	kg	%	%	%
1	16.82 ab	13.56 defg	-24	7.5	5.3
2	17.21 ab	15.61 abc	-10	8.3	9.9
3	15.33 cde	14.61 cdef	- 5	6.2	6.3
4	12.59 g	12.52 g	- 1	9.8	6.6
5	16.17 bcd	15.23 ab	- 6	7.2	10.0
6	13.44 fg	12.89 g	- 4	4.1	4.6
7	15.45 cde	14.78 cd	- 5	4.2	7.4
8	11.00 h	9.94 h	-11	6.6	6.7
20	15.69 bcd	14.73 cde	- 7	4.4	9.4
21	18.37 a	16.60 a	-11	4.5	6.5
22	16.46 bc	15.02 bcd	-10	4.0	3.7
23	16.04 bcd	15.17 abc	- 6	4.6	5.1
24	15.65 bcd	16.33 ab	- 4	6.7	5.2
25	14.03 efg	15.10 bc	7	5.4	3.9
26	14.78 def	15.57 ab	5	3.4	5.6
27	11.32 h	13.27 efg	15	13.0	4.4
28	12.69 g	13.20 fg	4	6.1	4.6
Mean	14.88	14.36	- 7.81	6.2	6.2
C.V.%	14	11	69	40	32
Minimum	11.00	9.94	0.56	3.39	3.72
Maximum	18.37	16.60	24.04	13.03	10.04
Range %	40	40	98	74	63

[a] $\frac{\text{New} - \text{Old}}{\text{New}} \times 100\%$; [b] $\frac{\text{Maximum} - \text{Minimum}}{\text{Maximum}} \times 100\%$

Different letters indicate real differences between varieties.

Table 11. Correlation and regressions (Y = aX + b) for objective measurements with old and new cells for 17 varieties.

Y	X	r	a	b
Shear new	Shear old	0.56	0.43	2.96
Compression new	Compression old	0.80	1.03	5.90
Compression old	Shear old	0.79	1.39	6.84
Compression new	Shear new	0.62	1.79	5.40
Compression new	Shear old	0.50	1.11	8.87
Compression old	Shear new	0.52	1.18	8.15

Table 12. Results of analysis of variance and Tukey's test for objective readings.

Measurement	Varieties included in analysis	M.S. error	F Actual value	F Value required	Tukey's least significant difference
Shear force new	1 to 8	0.0597	114	2.1	0.33
	20 to 28	0.1000	40	2.1	0.45
	1 to 8 + 20 to 28	0.0810	64	1.5	0.45
Shear force old	1 to 8	0.0778	142	2.1	0.38
	20 to 28	0.1119	45	2.1	0.48
	1 to 8 + 20 to 28	0.0959	91	1.5	0.48
Compression force new	1 to 8	1.0947	32	2.1	1.42
	20 to 28	0.7233	19	2.1	1.21
	1 to 8 + 20 to 28	0.8980	30	1.5	1.48
Compression force old	1 to 8	1.0815	44	2.1	1.41
	20 to 28	0.9768	46	2.1	1.41
	1 to 8 + 20 to 28	1.0261	42	1.5	1.59

Table 13. Comparison of ranking of varieties by objective measurements.

Rank[a]	Measurement:	Shear force				Shear compression			
	Cell:	Old		New		Old		New	
1		26	a	5	a	21	a	21	a
2		5	b	7	a	2	ab	24	ab
3		21	b	4	b	1	ab	2	ab
4		24	bc	22	b	22	bc	26	ab
5		25	cd	23	bc	5	bcd	5	ab
6		4	d	6	bc	23	bcd	23	ab
7		22	de	21	bc	20	bcd	25	bc
8		3	de	26	bc	24	bcd	22	bcd
9		23	de	24	bc	7	cde	7	cd
10		7	de	1	bcd	3	cde	20	cde
11		20	def	20	cde	26	def	3	cdef
12		28	ef	2	def	25	efg	1	defg
13		2	fg	3	efg	6	fg	27	efg
14		27	g	25	fg	28	g	28	fg
15		1	g	28	g	4	g	6	g
16		6	h	27	h	27	h	4	g
17		8	i	8	h	8	h	8	h

Column group heading: Variety (spanning Shear force and Shear compression).

[a]Varieties placed in order according to instrument reading.

Different letters indicate significant differences between varieties.

Table 14. Sensory rating scales.

Trait Scale	Firmness	Gumminess
1	extremely soft	no gumminess
2	very soft	slightly gummy
3	moderately soft	-
4	slightly soft	moderately gummy
5	slight firm	-
6	moderately firm	very gummy
7	very firm	-
8	extremely firm	extremely gummy

Table 15. Summary of sensory results for 9 varieties.

Variety	Firmness[c] Mean[a]	Firmness[c] C.V. %	Gumminess[d] Mean[a]	Gumminess[d] C.V. %
20	4.90 ab	6.5	3.66 abc	25.3
21	5.19 a	5.1	4.66 ab	23.2
22	4.98 ab	5.8	5.21 a	15.7
23	4.97 ab	8.4	4.10 abc	31.7
24	4.47 b	8.1	2.31 c	29.8
25	4.77 ab	9.2	3.69 abc	45.9
26	4.86 ab	9.1	2.96 bc	28.8
27	4.72 ab	7.3	4.10 abc	30.3
28	4.45 b	11.3	4.97 a	18.0
Mean	4.81	7.9	3.96	27.6
Minimum	4.45	5.1	2.31	15.7
Maximum	5.19	11.3	5.21	45.9
Range %[b]	14.3	54.9	55.7	65.8
F for significance at 5%	2.15	-	2.15	-
F value	2.74	-	5.11	-
Tukey's LSD	0.67		1.90	

[a]For 7 replicates; [b]$\frac{\text{Maximum - Minimum}}{\text{Maximum}}$ x 100%; [c]1 = extremely soft to 8 = extremely firm;

[d]1 = no gumminess to 8 = extremely gummy.

Different letters indicate real differences between varieties.

Table 16. Comparison of sensory and objective data

	Sensory		Objective					
			Shear force kg		Shear stress kg/mm		Shear compression kg	
Variety	Firmness	Gumminess	Old	New	Old	New	Old	New
20	4.9 a	3.66 a	5.29 cd	5.24 c	7.48	7.41	15.69 d	14.73 c
21	5.19 ab	4.66 a	6.31 b	5.66 ab	8.93	8.00	18.37 b	16.60 ab
22	4.98 ab	5.21 ab	5.68 cd	5.73 ab	8.04	8.11	16.46 bc	15.02 c
23	4.97 ab	4.10 abc	5.54 cd	5.69 b	7.84	8.04	16.04 cd	15.17 c
24	4.47 ab	2.31 abc	6.23 b	5.49 ab	10.88	9.60	15.65 bc	16.33 abc
25	4.77 ab	3.69 abc	5.75 c	4.68 ab	9.34	7.60	14.03 bc	15.10 bc
26	4.86 ab	2.96 abc	7.07 a	5.52 a	11.48	8.97	14.78 a	15.57 a
27	4.72 b	4.10 bc	4.67 e	3.94 d	6.60	5.57	11.32 e	13.27 d
28	4.45 b	4.97 c	5.24 d	4.52 d	8.51	7.34	12.69 e	13.20 d
Minimum	4.45	2.31	3.25	3.85	6.60	7.34	11.00	9.94
Maximum	5.19	5.21	7.07	6.36	11.48	11.54	18.37	16.60
Range %	14	56	54	39	42	36	40	40

Different letters indicate real differences between varieties.

Table 17. Correlation coefficients and regression equations (Y = ax + b) among sensory and objective readings for 9 varieties (20 - 28 table).

Y	X	r	a	b
Shear stress old	Firmness	0.21	1.02	11.05
Shear stress new	Firmness	0.02	0.06	5.84
Compression new	Firmness	0.45	2.16	4.64
Compression old	Firmness	0.69	5.81	-12.95
Shear new	Firmness	0.53	1.41	- 1.57
Shear old	Firmness	0.20	0.63	2.72
Shear stress old	Gumminess	-0.66	-0.82	9.42
Shear stress new	Gumminess	-0.50	-0.43	7.26
Compression new	Gumminess	-0.48	-0.60	17.41
Compression old	Gumminess	0.01	-2.91	15.11
Shear new	Gumminess	-0.12	-0.08	5.53
Shear old	Gumminess	-0.50	-0.41	7.36

Table 18. Comparison of variety ranking by objective and sensory measurements.

Rank[a]	Variety					
	Sensory		Objective			
			Shear force		Shear compression	
	Firmness	Gumminess	Old	New	Old	New
1	21 a	22 a	26 a	22 a	21 a	21 a
2	22 ab	28 a	21 b	23 ab	22 b	24 ab
3	23 ab	21 ab	24 b	21 ab	23 bc	26 abc
4	20 ab	23 abc	25 c	26 ab	20 bc	23 bc
5	26 ab	27 abc	27 cd	24 ab	24 bc	25 c
6	25 ab	25 abc	23 cd	20 b	26 cd	22 c
7	27 ab	20 abc	20 cd	25 c	25 d	20 c
8	24 b	26 bc	28 d	28 c	28 e	27 d
9	28 b	24 c	27 e	27 d	27 e	28 d

[a]Ranked according to test reading.

Different numbers indicate real differences between varieties.

Table 19. Comparison of 1971 and 1972 data for optimum cooking time and diameter before and after cooking.

Variety	Optimum cooking time			Diameter before cooking			Diameter after cooking			Change in diameter[b]		
	1971 min	1972 min	Difference[a] %	1971 mm	1972 mm	Difference[a] %	1971 mm	1972 mm	Difference[a] %	1971 %	1972 %	Difference[a] %
1	11.0	11.0	0	1.7	1.6	5.9	2.7	2.5	7.4	59	56	5.1
2	11.0	11.0	0	1.8	1.6	11.1	3.0	2.8	6.7	67	75	-11.9
3	12.0	12.0	0	1.8	1.7	5.6	3.0	2.8	6.7	67	65	3.0
4	18.0	19.0	- 5.6	2.0	1.8	10.0	3.0	3.1	-3.3	65	72	-10.8
5	12.0	16.0	-33.3	1.8	1.9	- 5.6	2.9	3.1	-6.9	61	72	-18.0
6	10.0	12.0	-20.0	1.6	1.5	6.3	2.6	2.5	3.8	63	67	- 6.3
7	17.0	15.0	11.8	1.8	1.7	5.6	3.0	3.0	0	67	76	-13.4
8	11.0	11.0	0	1.4	1.3	7.1	2.4	2.5	-4.2	71	92	-29.6

[a] $\frac{1971 - 1972}{1971} \times 100\%$

[b] $\frac{\text{diameter after} - \text{diameter before}}{\text{diameter before}} \times 100\%$

Table 20. Comparison of 1971 and 1972 data for shear force and shear stress recorded in the old multiblade shearing cell.

Variety	Shear force[a]			Shear stress[a]		
	1971 kg	1972 kg	Difference[b] %	1971 g/mm^2	1972 g/mm^2	Difference %
1	3.56	4.60	-29.2	6.20	9.37	-51.1
2	4.59	4.96	- 8.1	6.50	8.06	-24.0
3	4.48	5.68	-26.8	6.30	9.22	-46.3
4	5.60	5.73	- 2.3	6.50	7.59	-16.8
5	4.56	6.54	-43.4	6.90	8.66	-25.5
6	3.96	4.04	- 2.0	7.50	8.23	- 9.7
7	5.51	5.51	0	7.80	7.80	0
8	2.74	3.25	-18.6	6.00	6.62	-10.3

[a] Mean of 10 replicates

[b] $\frac{1971 - 1972}{1971} \times 100\%$

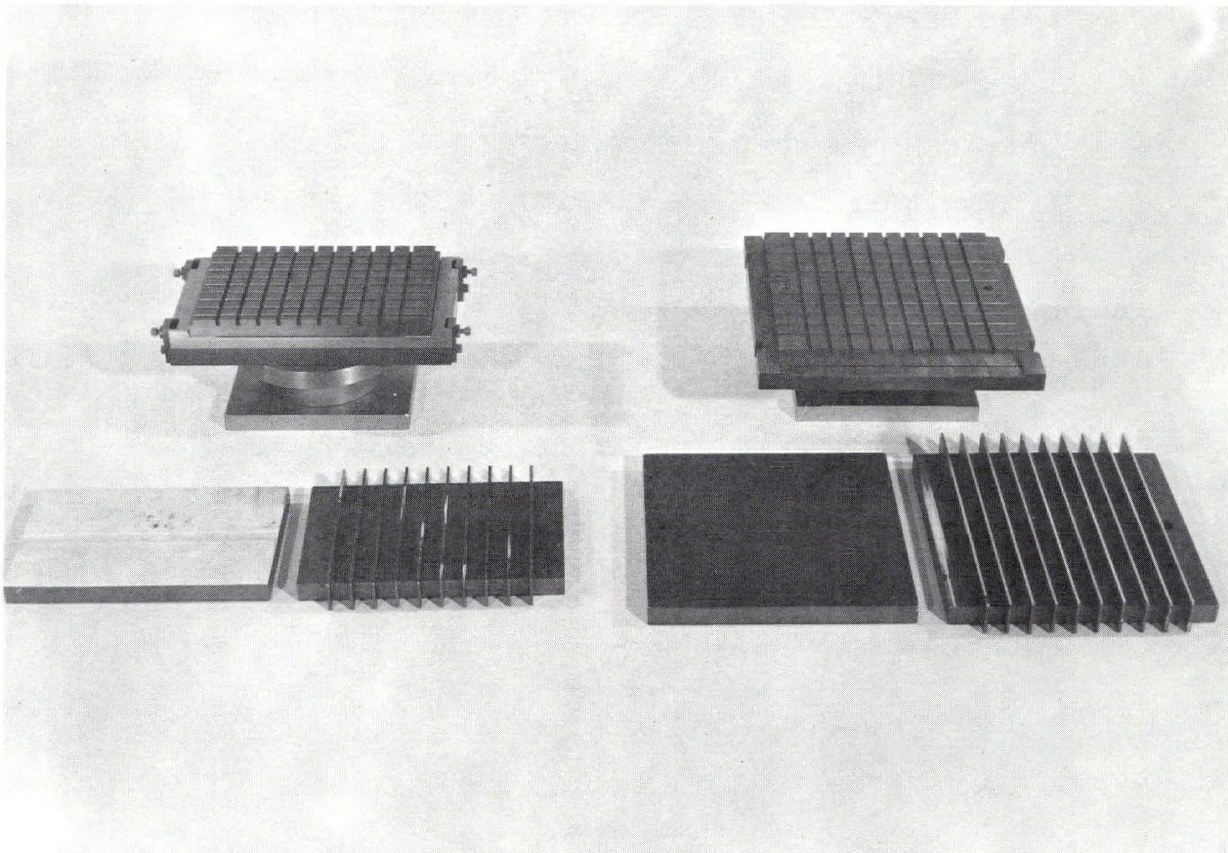

Figure 1. Comparison of old and new spaghetti test cells.

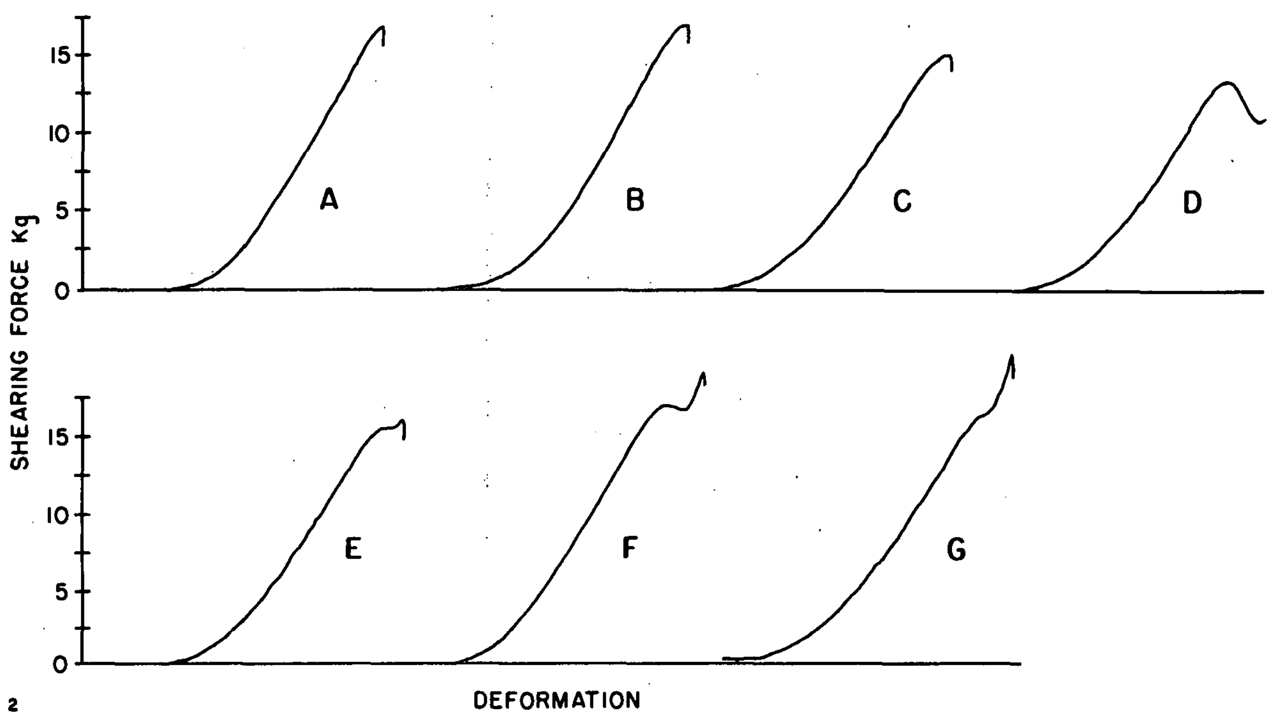

Figure 2. Typical records of force against distance of the shearing blade from the plate. A. variety 4 clearance 0.762 mm; B. variety 4 and C. variety 5 - clearance 0.508 mm; D. variety 4 and E. variety 5 - clearance 0.254 mm; F. variety 4 and G. variety 5 - clearance 0.152 mm.

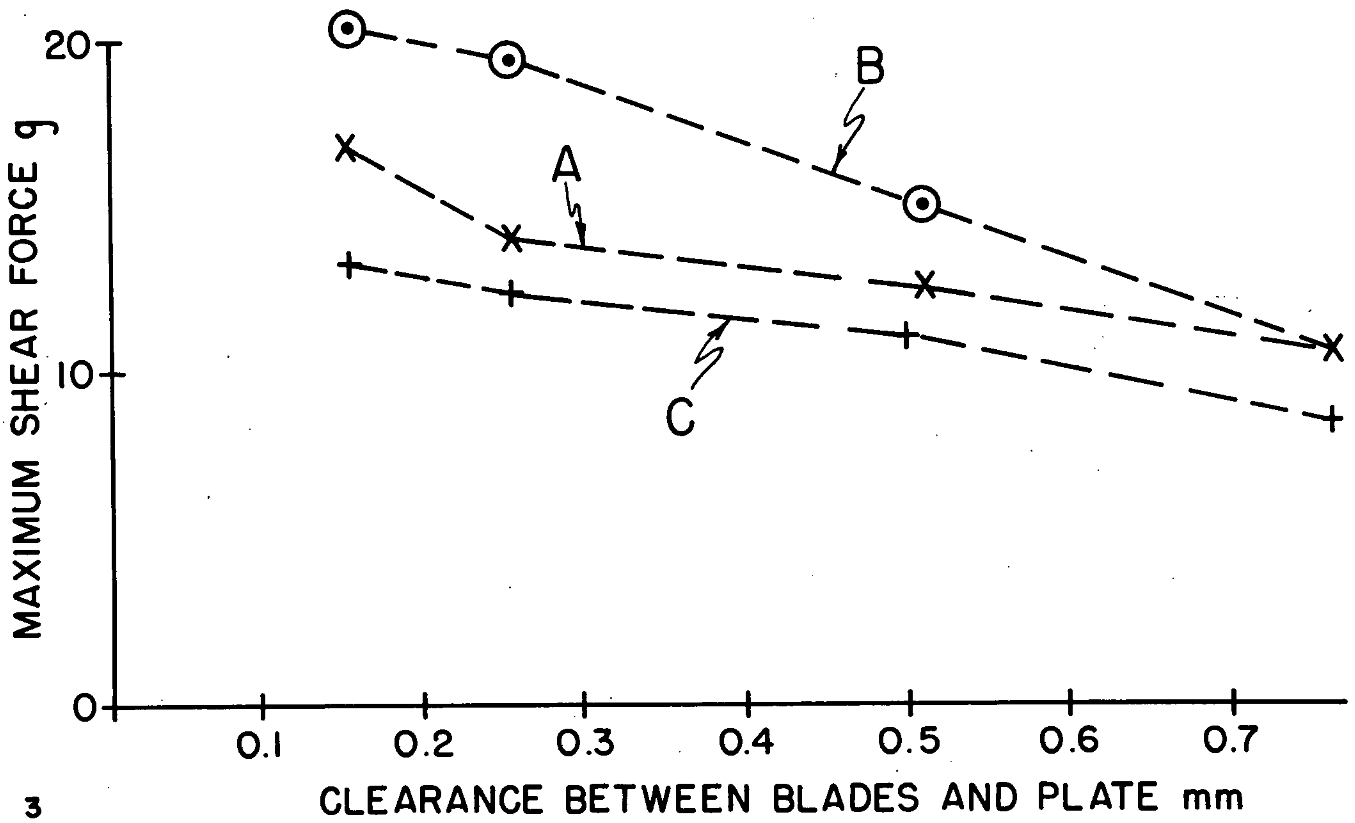

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Figure 3. A. Maximum shear force vs clearance between blades and plate. Each point is the mean of a single sample of 12 varieties; B. same for variety No. 22; C. same for variety No. 8.

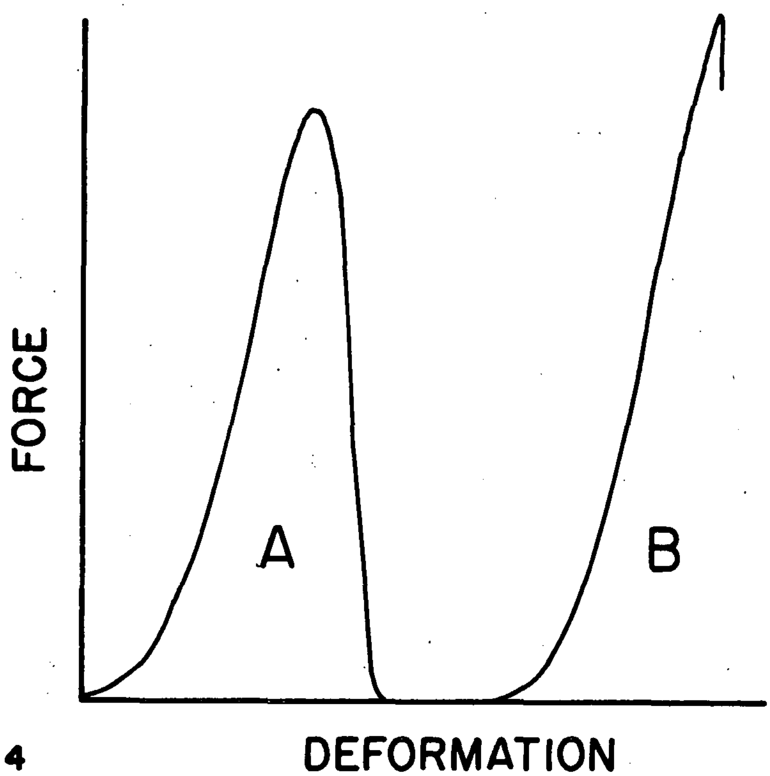

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Figure 4. Typical examples of curves. A. rounded-variety 4 blade 0.8128 mm thick, clearance 0.254 mm; B. sharp - variety 1 blade 0.254 mm thick, clearaace 0.508 mm

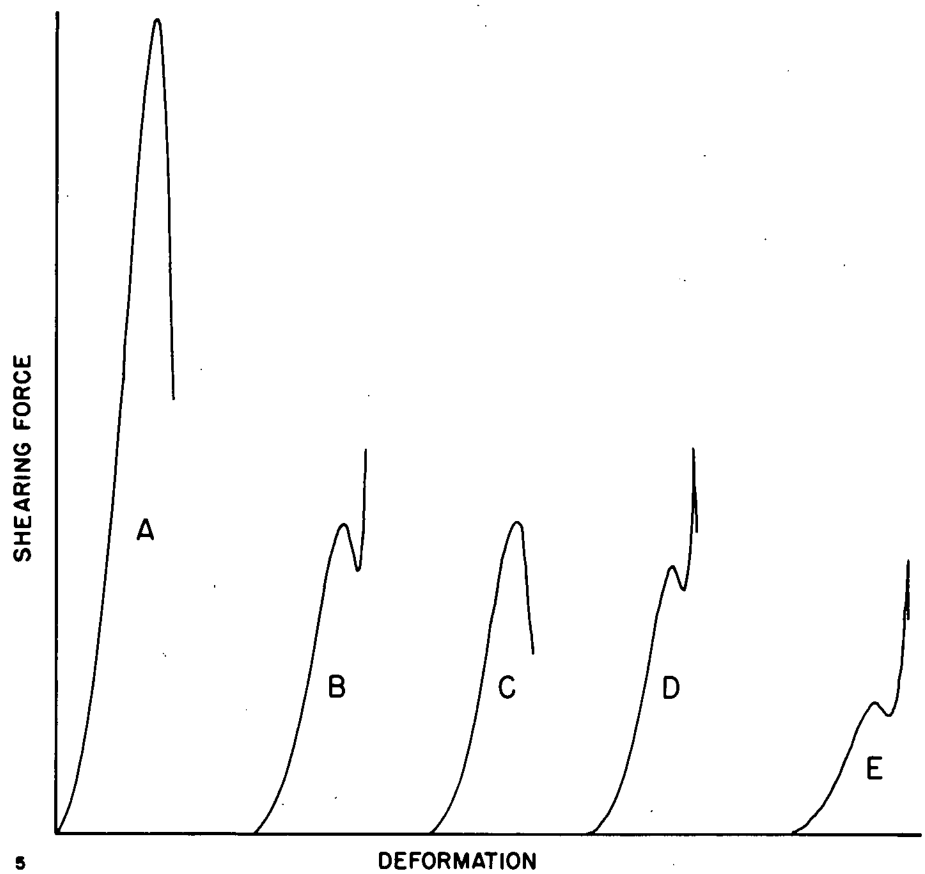

Figure 5. Typical records showing effect of blade thickness on characteristic force-deformation curve shape for a blade clearance of 0.1524 mm at thicknesses of A. 0.254 mm; B. 0.635 mm; C. 0.8128 mm; D. 1.016 mm; E. 1.5748 mm. Variety No. 1

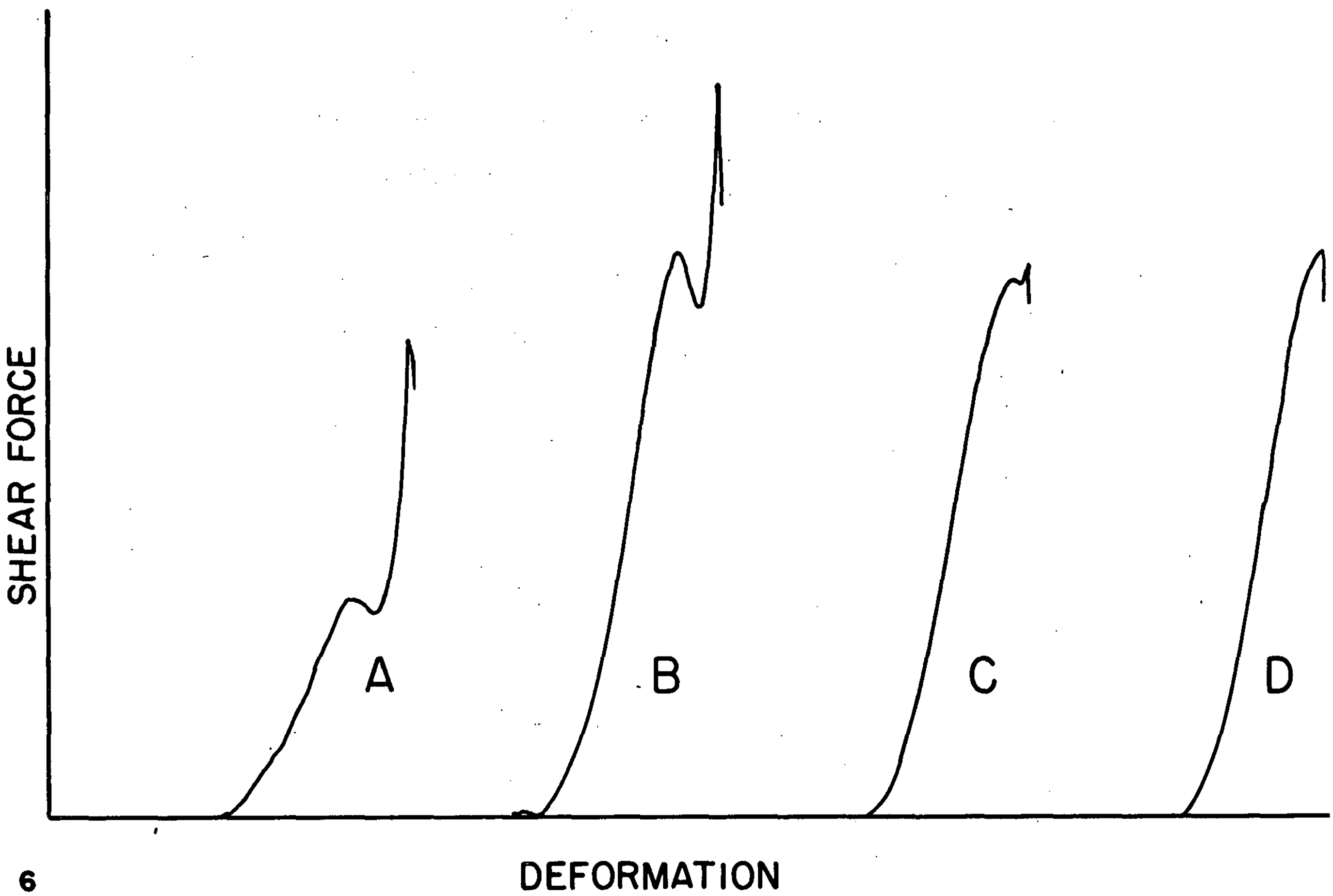

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Figure 6. Typical records showing effect of blade clearance on characteristic force-deformation curve shape for blade 1.5748 mm thick at clearances of A. 0.1524 mm; B. 0.254 mm; C. 0.508 mm; D. 0.762 mm. Variety No. 1. Vertical axis is not to scale. A is 2.5 less than the other curves.

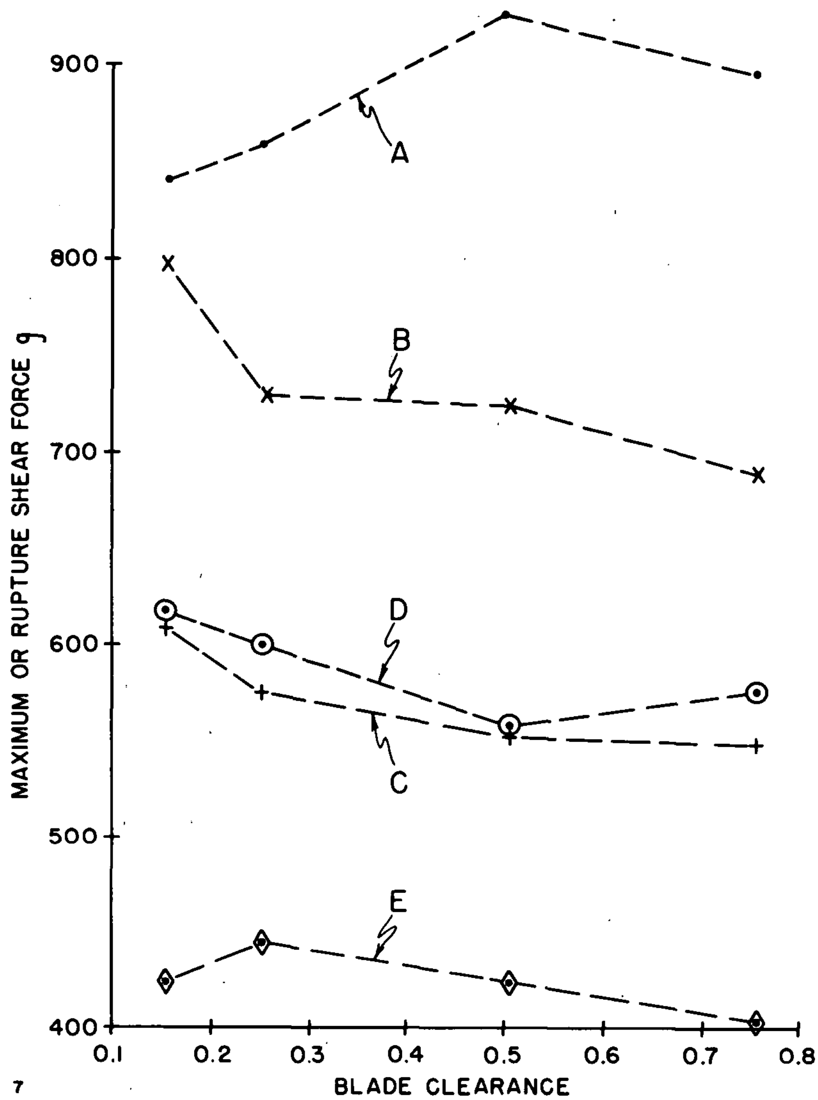

Figure 7. Effect of blade clearance on maximum or rupture force. Each point is the mean of 5 samples of 4 varieties (1, 4, 5 and 23) at blade thicknesses of A. 1.5748 mm; B. 1.016 mm; C. 0.8128 mm; D. 0.635 mm; E. 0.254 mm.

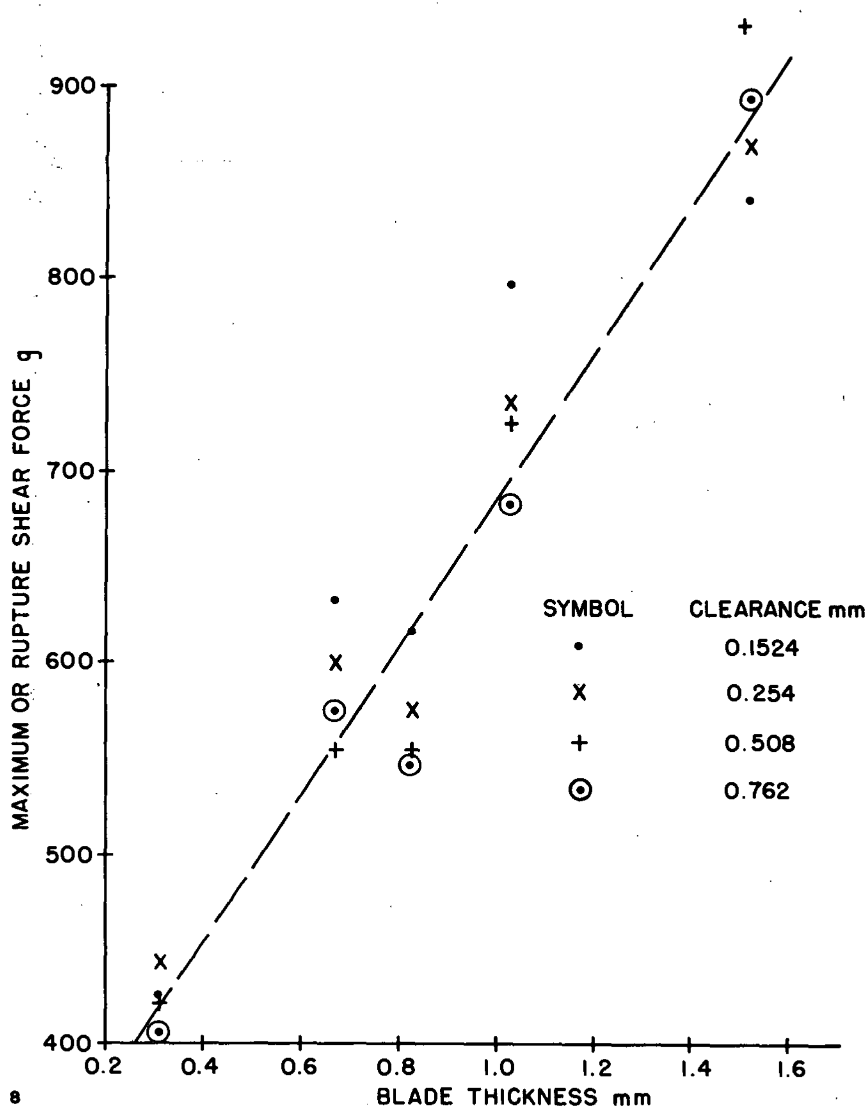

Figure 8. Effect of blade thickness on force at four blade clearances. Each point is the mean of 5 samples of four varieties (1, 4, 5 and 23).

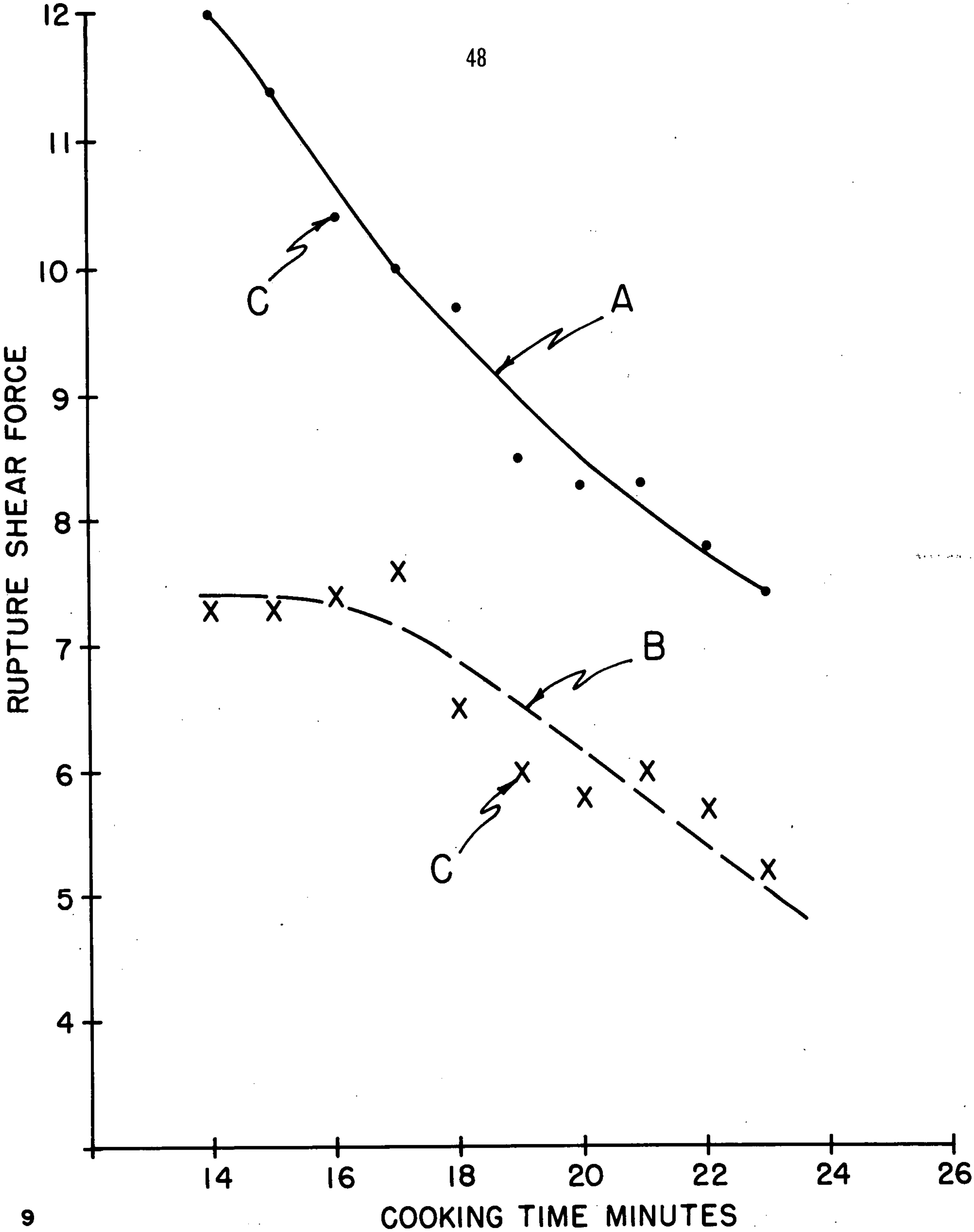

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Figure 9. Effect of cooking time on rupture shear force in the multiblade shear compression cell using a clearance of 0.1524. A. variety No. 5; B. variety No. 4; C. is optimum cooking time. Each point is for one sample.

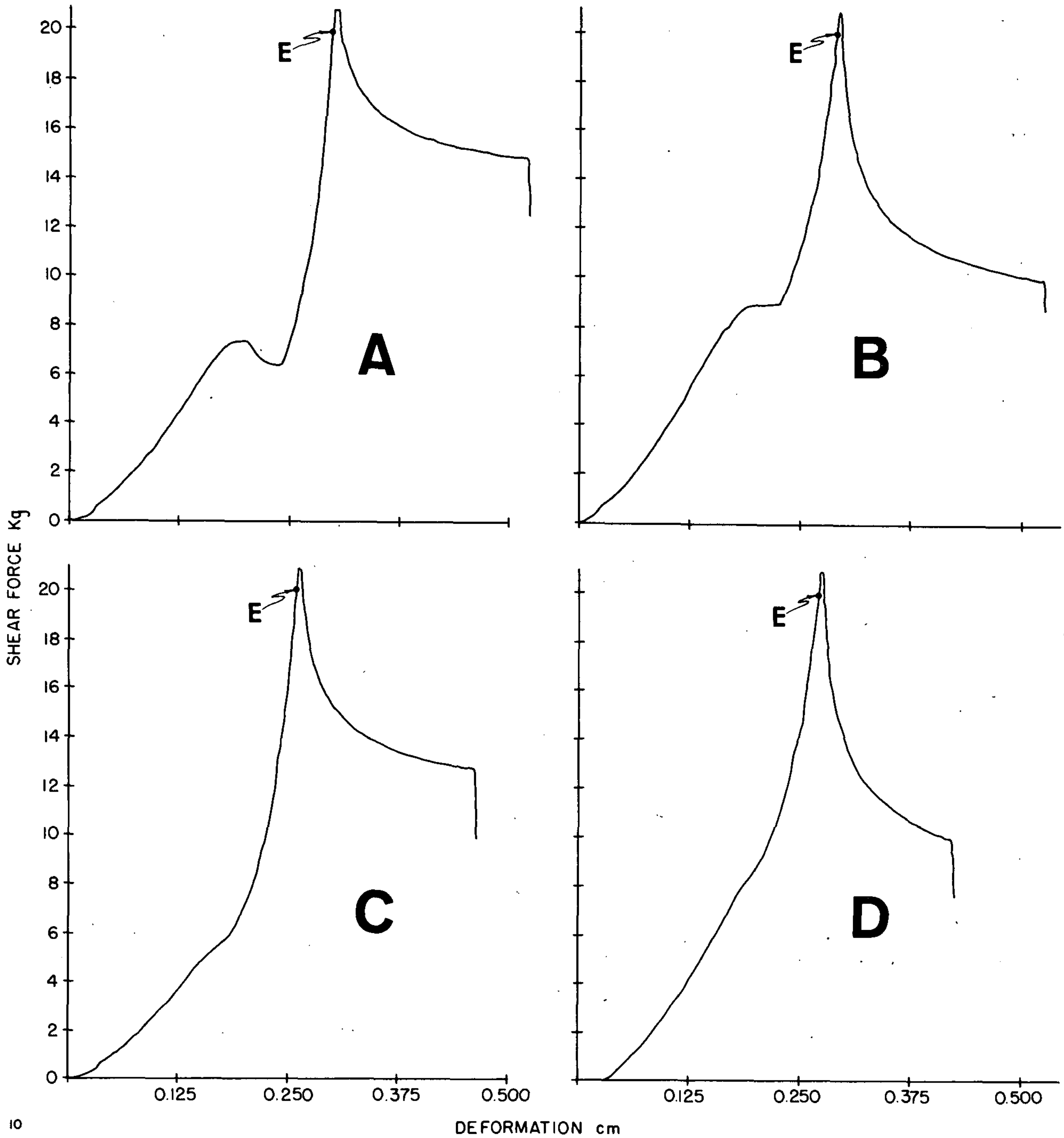

Figure 10. Typical results obtained by stopping the crosshead when the force applied was 20 kg for varieties A. 4; B. 5; C. 27; D. 28; E. is point where force was 20 kg and some overshoot occurred.

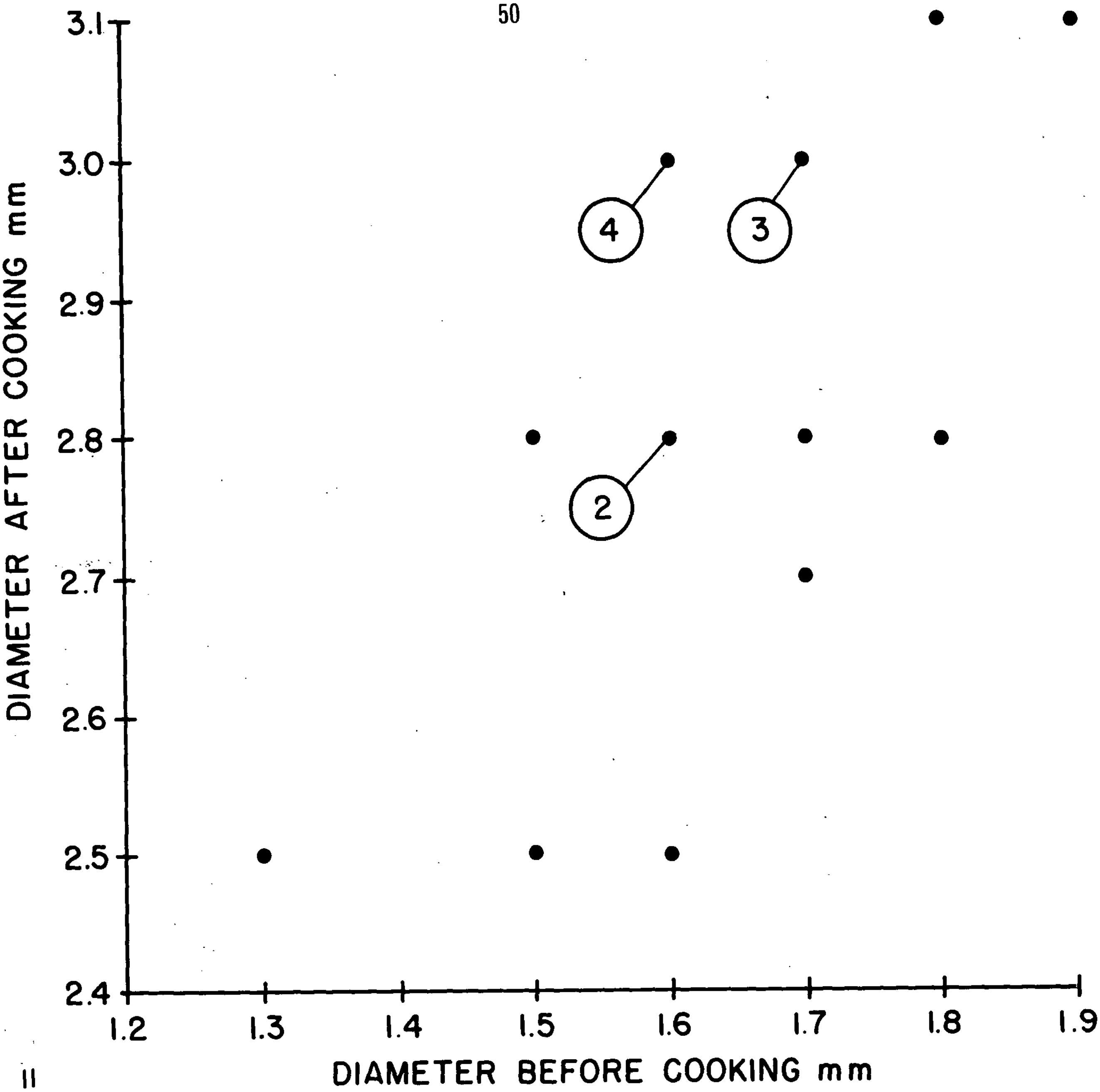

Figure 11. Relationship between stick diameter before and after cooking. Numbers indicate number of varieties (greater than one) at each point.

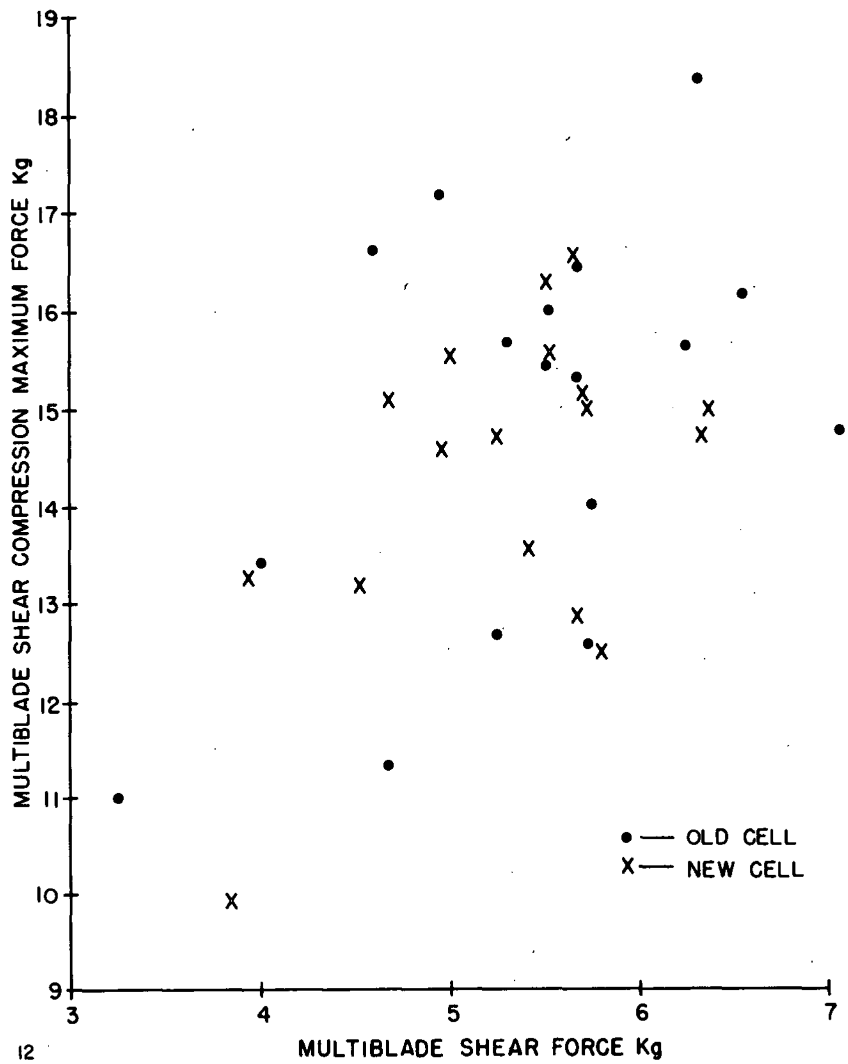

Figure 12. Plot of shear force Vs maximum shear compression force for new and old cells. Each point is the mean of 10 samples.

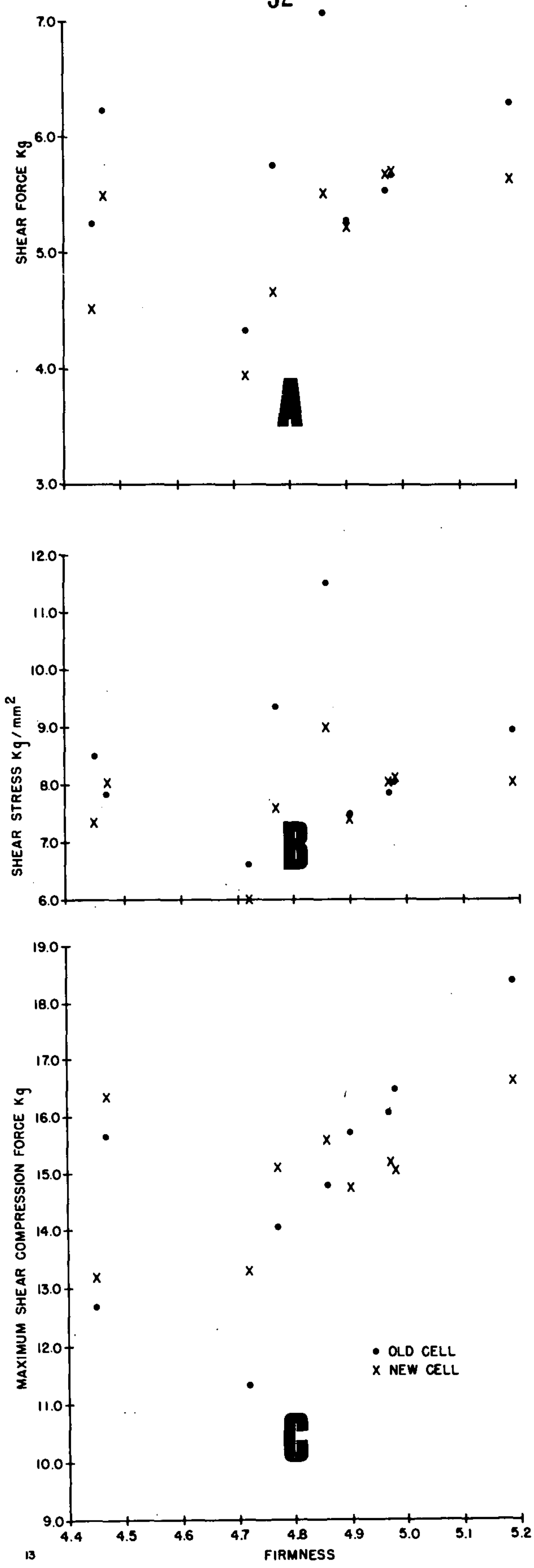

Figure 13. Plots of objective (mean of 10 replicates) and sensory firmness (mean of of 7 replicates) readings for both old and new cells. A. shear force; B. shear stress; C. maximum shear compression force.

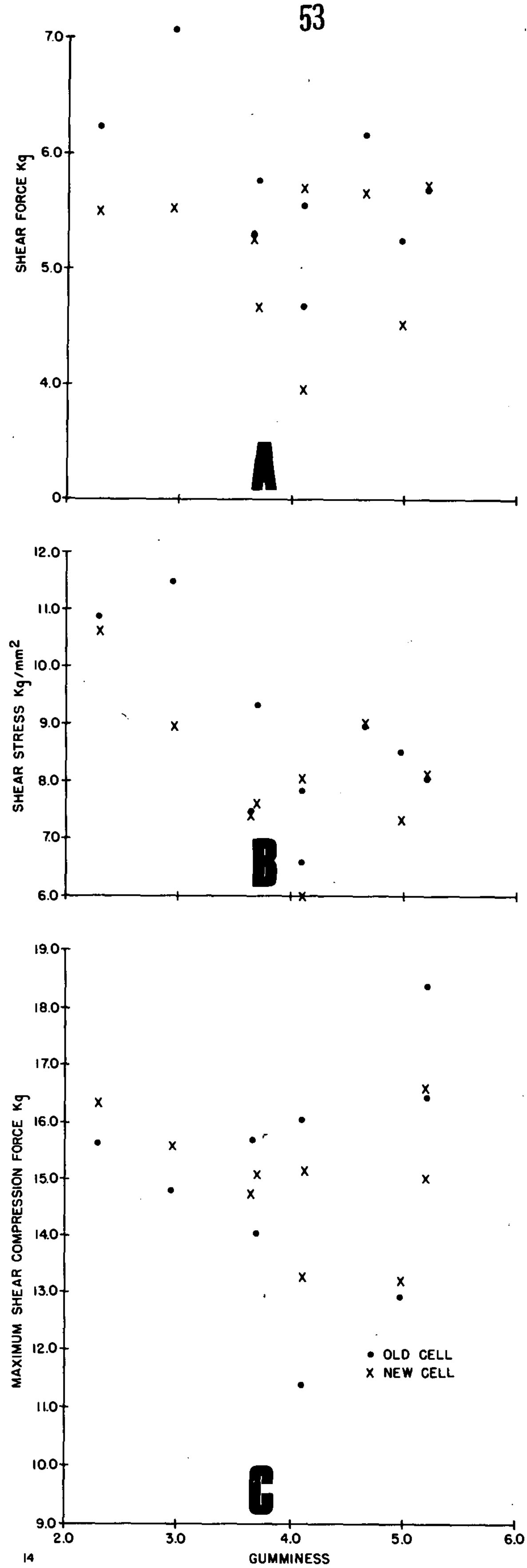

Figure 14. Plots of objective (mean of 10 replicates) and sensory gumminess (mean of 7 replicates) readings for both old and new cells. A. shear force; B. shear stress; C. maximum shear compression force.