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A method for measuring tomato fruit firmness using a modified shear press

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Summary

Tomato fruit firmness was measured with a modified shear press by compressing individual fruit by 5 mm between two flat surfaces. The system was calibrated with a spring balance and the relationship between applied force and proving ring deformation was linear over the range tested.

The correlation coefficient between tomato fruit firmness as measured by a finger feel panel and the shear press was 0.988. Minimum shear press firmness values for acceptability of fruit for sale at retail level and use in the home were obtained by matching the panel and shear press data.

Tests showed that from fifteen to twenty-five fruit should be tested per 12-lb box to get a good estimate of the average firmness of the lot. The spread of firmness values on either side of the mean was considerable in the nineteen lots tested and it is important to quantify this and quote it, in addition to the mean firmness value, to give a complete picture of tomato fruit firmness.

The system described is useful for carrying out firmness tests on tomato fruit cultivars at time of picking and during storage in order to obtain an estimate of potential shelf-life during wholesaling and retailing.

Introduction

The production costs of tomatoes grown under glass are continuing to rise with consequent higher retail prices. Consumers are, therefore, demanding a higher level of quality. Growers are looking for higher yielding cultivars and modified methods of production in an effort to cut costs, and in such a situation there is a danger that quality may be impaired. There is increasing emphasis at both wholesale and retail level on the importance of tomato fruit firmness, especially in produce that is to be, or has been, exported, and it is important that simple practical methods are available to measure fruit firmness.

Voisey (1971) has reviewed the modernization of texture instrumentation, including various systems for carrying out compression tests. Holt (1970) described a technique

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of punch testing tomatoes to measure the firmness of the different anatomical parts. Hamson (1952) measured the amount of tomato fruit compression for a fixed load, while Shafsak & Winsor (1964) carried out a similar test on the fruit along an axis from the calyx to the stylar scar. Other firmness meters for tomatoes, the Firm-o-meter and the Anso meter were described by Garrett *et al.* (1960). Diener, Sobotka & Watada (1971) measured tomato fruit firmness with a modification of the original P-L meter. The readings compared favourably with those obtained with the Instron Universal Testing machine. Voisey, Buckley & Crete (1974) described a system to record food deformation automatically between two levels of applied force. Philouze (1975) used a penetrometer technique to measure the firmness of thirty-eight tomato fruit cultivars. Stenvers, Rudolphij & Bruinsma (1973) designed a non-destructive, automated, fast and portable softness measuring device which measures tomato fruit firmness at the stylar scar.

The present study reports a simple modification of the shear press, using the strain gauge system described by Keppel & Gormley (1975) coupled to a high gain instrumentation amplifier. Each tomato fruit was compressed through 5 mm at a constant rate between a plunger attached to the proving ring and a flat metal plate on top of a laboratory jack. The force to achieve this compression was measured and the correlation between the instrument and a 'finger feel' panel was very high. Minimum firmness levels for acceptability of tomatoes at retail level or for use in the home are given.

Materials and methods

Modification and operation of the shear press

A shear press with a 58-kg proving ring with attached strain gauges as outlined by Keppel & Gormley (1975) was modified for use in these compression tests. The operational amplifier used with the system described by the authors above proved inadequate due to the limitations of gain versus input impedance. A Burr Brown 3660K instrumentation amplifier was used to overcome this. A schematic diagram of the strain gauge bridge and amplifier is shown in Fig. 1. The amplifier has adjustable voltage gain set by resistor R_G .

$$\text{Gain equation } G = \frac{10^5}{R_G} V/V \text{ (adjustable between 1 and 1000)}$$

$$\text{(Output voltage) } E_0 = GE_i \text{ (Differential Input Voltage)}$$

$$E_0 = \frac{10^5 E_i}{R_G}$$

An optional offset adjustment using a 100 kohm potentiometer between terminals 7, 6 and the negative supply rail was used to provide any desired offset. A range control was provided on the output by means of a 1 k Ω potentiometer in series with a

FIG. 1. Schematic diagram of strain gauge bridge and amplifier.

5 k Ω resistor. The complete system is mains operated from a stabilized power supply which provides ± 15 V for the amplifier and +12 V E_s to power the bridge circuit. The amplifier was connected to a Philips PM8100 flatbed recorder.

FIG. 2. Shear press compression system.

The arrangement used for compressing the tomato fruit is shown in Fig. 2. A plunger (a) from a standard succulometer cell is attached to the proving ring. A thin piece of sheet aluminium (b), in the form of a bridge, is placed on the ledge (c). The height of the 'legs' (d) is such that the bridge is exactly 5 mm above the point of lowest descent of the plunger (a). The tomato fruit to be tested is placed on the screw jack (f) and is elevated until it touches the bridge (b). The bridge is then removed and the plunger is activated thereby compressing the tomato by 5 mm. The deformation of the proving ring is recorded on a strip chart and the force peak rises to a maximum and falls off again during the compression of the fruit. A ram speed of 4.5 mm per second was used in all tests. The orientation of the tomato fruit during the compression was such that the line joining the styler scar to the calyx was horizontal. A sample of twenty-five fruit can be tested in a period of 10 min using this system.

Linearity and calibration

A standardized 10-lb Salter spring balance was used to calibrate the system and check it for linearity. The hook of the spring balance was placed under the bottom of the plunger (a) (Fig. 2) and an operator pulled the spring up vertically until the balance was recording 1 lb (proving ring system static). When a steady 1 lb force was attained, as indicated by a horizontal straight line on the strip chart, the height of the straight line from the baseline was measured. The procedure was repeated for spring balance readings of 2–10 lb at 1 lb intervals thus giving a set of parallel lines. The heights of these lines on the recorder were noted, thus measuring the deformation of the proving ring under forces from 1 to 10 lb. Each force (from 1–10 lb) was applied three times, thus giving thirty applications in all. It was necessary to change the span adjustment on the recorder during these tests in order to keep the straight lines on the paper for the different forces applied.

Correlation with finger feel

Correlation of the shear press system with subjective finger feel tests was carried out using tomatoes carefully selected on the basis of colour and size. Twelve fruit at the green/yellow stage were picked (cv. Eurocross BB) every second day from a glasshouse over a period of eighteen days, giving a total of ten batches or 120 individual fruit. Each fruit was individually coded with a small stick-on label. All the fruit were uniformly round and were in the size range 50–52 mm in diameter. They were stored in a room at 18°C after picking. On the eighteenth day the fruit were presented to a twelve-member panel (six males and six females) experienced in tomato production and marketing who were asked to place the fruit in order (1 to 10) from firmest to softest on the basis of finger feel. The rank numbers given to fruit of the same age by the twelve panelists were added, thereby giving a firmness rating to the ten sets of tomatoes. The tests took place in a dark room (to remove the influence of colour, and to make the codes invisible) and each panelist received a set of fruit that ranged from firm (just

picked) to very soft (eighteen days old). When each panelist had completed his or her assessment the same fruit were then compressed individually on the shear press and the peak heights on the strip chart corresponding to each compression were measured. The peak heights for tomatoes of the same age post-harvest were added together and the order of firmness obtained with the shear press was correlated (rank method) with that obtained by the panel.

Acceptability levels

In addition to putting the ten fruit in order from firmest to softest the panelists were also asked to indicate (i) the break point in firmness between suitability and non-suitability for sale at retail level and (ii) the break point between usable and not usable in the home, i.e. too soft to slice, or only suitable for stews or puree. In this way it was possible to assign acceptability categories in terms of grams force for a 5 mm tomato fruit compression.

Fruit size and firmness reading

Tomato fruit were placed in seven categories on a weight basis and were then stored at 18°C for eight days. There were from 27 to 31 fruit in each category, made up as nearly as possible by equal numbers of fruit of three cultivars. The seven categories were from 31–40 g, up to 91–100 g in 9 g ranges. Average firmness values (g force) for the fruit in each size category were calculated from the individual results.

Destructive nature of measurements

The destructive nature of the compression test was investigated by carrying out five successive compressions on individual tomatoes, each one 15 sec after the previous one. The tomatoes used were stored at 18°C. All compressions on individual tomatoes were made without changing the position of the tomato on the platform of the screw jack; it was necessary, however, to raise each tomato slightly in order to make it touch the 'bridge' again after the first compression.

Further tests were carried out on eight day-old tomatoes, where three successive compressions were made on each fruit with an interval of 1 hr between them.

Sample size for a given precision

Nineteen different tests were carried out to find the number of fruit needed to obtain a firmness result of a desired precision. Various combinations of age of fruit post harvest, number of fruit per test, and different cultivars were investigated in order to obtain as wide a range of samples as possible. Details of the different combinations are given in Table 5 in the results section. Fruit used in these tests were taken from 12 lb trays of commercially grown tomatoes. The firmness values for tomatoes in each test were used to calculate the standard deviation, using the range method of Kramer & Twigg (1966)

for that test. This figure was then entered in the variables sampling equation (Kramer & Twigg, 1966):

$$n = \left(\frac{ks}{\epsilon} \right)^2$$

where k = the number of standard deviations, s = standard deviation, ϵ = the desired precision and n = the number of samples that need to be tested for a result of a desired precision. A value of 1.65 (90% assurance) was chosen for k and $\pm 7\%$ for ϵ . These values were used in the above equation when computing the results of all tests. The appropriate value of s was entered in the equation for each test, and the number of fruit per sample (n) that needed to be compressed to ensure that the firmness value would be within $\pm 7\%$ from the true value for the lot 90% of the time was calculated.

The percentage of fruit within a given lot (12 lb) whose firmness fell within ± 5 , ± 10 , ± 15 , $\pm 20\%$ of the mean firmness value for the lot (i.e. the spread of values around the mean) was calculated from the data for the nineteen tests described in Table 5.

Results

Linearity and calibration

The results (Table 1) show that the relationship between applied force and proving ring deformation was linear in the range tested. Since the 100 mV recorder span setting was found most suitable for tomatoes, the system was calibrated using this part of the data. The applied forces (1–6 lb) were added together, as were the corresponding straight line heights. One pound was equivalent to a line height of 32 mm, or 1 mm was equivalent to 14.2 g force.

TABLE 1. Chart recorder line heights (mm, mean values) for different forces applied to the proving ring with a spring balance

Applied force (lb)	Recorder span setting (mV)			
	20	50	100	200
1	163	65 (1)*	32 (1)*	16 (1.000)*
2	—	129 (1.985)	63 (1.969)	32 (2.000)
3	—	193 (2.969)	97 (3.031)	48 (3.000)
4	—	—	128 (4.000)	64 (4.000)
5	—	—	162 (5.063)	80 (5.000)
6	—	—	194 (6.063)	97 (6.063)
7	—	—	—	113 (7.063)
8	—	—	—	129 (8.063)
9	—	—	—	145 (9.063)
10	—	—	—	164 (10.250)

* The figures in brackets are ratios obtained by dividing the top number in each column into the subsequent ones.

Correlation with finger feel

The rank correlation coefficient between tomato fruit firmness as measured by a finger feel panel and the shear press was 0.988. The spread of firmness values for the shear press was satisfactory, and the proximity of one value to the one above or below it (Table 2) was generally of the same order as that in the corresponding panel scores, except in the case of the firmest tomatoes.

TABLE 2. Mean panel and shear press values for tomato fruit firmness

Age of tomatoes post-harvest (days)	Panel firmness score*	Shear press values (g force)**
0	12 (1)	1686 (1)
2	28 (2)	1304 (2)
4	37 (3)	1063 (3)
6	60 (4)	808 (5)
8	62 (5)	822 (4)
10	71 (6)	737 (6)
12	80 (7)	652 (7)
14	90 (8)	638 (8)
16	109 (9)	581 (9)
18	111 (10)	553 (10)
Rank correlation: panel $\times$ shear press = 0.988		

* Twelve panelists; firmest sample score 1, softest 10.

** Mean value for twelve fruit.

Acceptability levels

The break point in fruit firmness between suitability and non-suitability for sale at retail level was taken at 680 g force, while that for tomatoes usable in the home, i.e. capable of being sliced easily, was 540 g. These figures are based on the evaluation of the finger feel panel.

Fruit size and firmness reading

The results (Table 3) show that the tomatoes in the two smallest size grades were more compressible than those in the larger grades and suggest that fruit weighing over 50 g are most suitable for testing, if the sample is not size graded.

Destructive nature of test

Even though the test was non-destructive in that it did not damage the fruit visibly, it did cause some permanent change in the shape of the tomatoes. This was discovered when making the second compression, when it was found necessary to re-adjust the

TABLE 3. Effect of tomato fruit* size on the firmness reading

No. of fruit tested	Size (g)	Shear press value (g force)
29	31-40	1006
29	41-50	1020
31	51-60	1063
27	61-70	1105
31	71-80	1148
31	81-90	1091
29	91-100	1162

* The fruit were held for eight days post-harvest at 18°C.

tomato upwards slightly on the screw jack in order to make it touch the bridge. This indicated that the tomato had not returned completely to its pre-compression size. The firmness values for tomatoes that received successive compressions (Table 4) confirm this finding, as the mean firmness value increased considerably between the first and second compressions and to a lesser extent between the others. A similar trend was found for tomatoes that received three successive compressions, each separated by 1 hr, with firmness values of 836, 935 and 1034 g respectively.

TABLE 4. Firmness (g force) of tomatoes subjected to five successive* compressions

Age of fruit post-harvest (days)	Compression				
	1	2	3	4	5
0	1331	1587	1559	1629	1672
4	1275	1629	1601	1573	1615
8	1006	1162	1176	1304	1318
12	1063	1261	1346	1261	1261
16	694	893	878	907	893
20	581	723	751	793	779
Mean	992	1209	1219	1245	1256

* Fifteen seconds between each compression.

Sample size for a given precision

The data (Table 5) show the number of fruit from a 12 lb lot that need to be tested to ensure that the results obtained will be within $\pm 7\%$ of the true firmness value of the lot 90% of the time. The number of fruit (n) required for the sample varied from 8 in

9.8067

TABLE 5. Fruit number* to be tested for a firmness result of a desired precision**

Test	Age of fruit post-harvest (days)	No. of fruit tested	Size (g)	Cultivar	Mean firmness (g)	Range (g)	Precision $\pm \varepsilon$	SD	<i>n</i> (Sample number)
1	7	30	31-40	Mixed	1008	710	71	170	16
2	7	30	41-50	Mixed	1022	767	72	184	18
3	7	30	51-60	Mixed	1065	724	75	174	15
4	7	25	61-70	Mixed	1108	667	78	160	12
5	7	30	71-80	Mixed	1150	710	81	170	12
6	7	30	81-90	Mixed	1093	894	77	214	21
7	7	30	91-100	Mixed	1164	554	81	133	8
8	4	100	50-90	Mixed	1193	1093	84	262	27
9	8	100	50-90	Mixed	937	834	66	200	25
10	12	100	50-90	Mixed	852	738	60	177	24
11	8	26	50-90	Grenadier	1108	653	78	157	11
12	8	24	50-90	Sonato	1079	586	76	136	9
13	8	21	50-90	Eurocross BB	951	483	67	116	8
14	12	27	50-90	Grenadier	895	525	63	126	11
15	12	24	50-90	Sonato	880	497	62	119	11
16	12	21	50-90	Eurocross BB	795	456	56	109	11
17	16	25	50-90	Grenadier	880	653	62	157	18
18	16	24	50-90	Sonato	809	469	57	112	11
19	16	21	50-90	Eurocross BB	738	525	52	126	16

* From a 12 lb box.

** Ninety per cent assurance $\pm 7\%$ from the mean firmness value.

Tomato fruit firmness

tests number 7 and 13 to 27 in test 8 (Table 5). On the basis of the data in Table 5 it seems that a sample of twenty-five fruit should be sufficient to predict the firmness of most lots with reasonable accuracy and this sample number will be used in future tests with this system. A sample size of fifteen would probably suffice if the fruit were of one cultivar.

The percentages of fruit within a 12 lb lot (averaged over the nineteen lots in Table 5) whose firmness fell within ± 5 , ± 10 , ± 15 and $\pm 20\%$ of the mean firmness value for that lot were 27, 50, 60 and 80% respectively. For example, if a lot had a firmness value of 1000 g, 50% of the fruit would be within the firmness range $1000\text{g} \pm 10\%$ (900–1100) and 80% would be within the range $1000 \pm 20\%$ (800–1200 g).

Discussion

The shear press system described in these tests proved very satisfactory for measuring tomato fruit firmness and the instrumentation amplifier allowed the small compression forces involved to be recorded. The system is easy to calibrate and the relationship between applied force and that which was sensed and recorded was excellent. Some of the problems of amplifier sensitivity (see 'Materials and Methods') arose from having a 'heavy' proving ring on the shear press; this one was appropriate for loads up to 58 kg, far in excess of the load required for tomato testing. It should be noted that a lighter ring would be more suitable if one was available.

A fruit compression of 5 mm was chosen in these tests because it seemed similar to the amount of compression that a potential purchaser would use at the point of retail sale. It resulted in firmness readings of 1700 to 550 g, depending on the age of the fruit post-harvest. Voisey & Crete (1973) used tomatoes mounted on a transducer to measure the type of forces consumers were likely to use in evaluating firmness. They found the maximum force (mean) used by thirty-one panelists was 1617 g. This was close to the maximum readings of 1700 g found in practice using the shear press system in these tests. The compression tests were carried out on fruit at right angles to an axis from the calyx to the stylar scar, rather than at the stylar scar itself, as practiced by Stenvers *et al.* (1973), because it was felt that this procedure was closest to consumer evaluation. The decision to use a 5 mm compression and a calyx-stylar scar fruit orientation was endorsed by the high correlation between the shear press system and a finger feel panel.

The firmness readings on tomatoes were influenced by fruit size in that fruit (of a given age post-harvest) less than 50 g in weight gave slightly lower firmness values than those above 50 g. In some cases it may be necessary to grade fruit into different size categories, depending on the accuracy required. Shafsak & Winsor (1964) reported a similar trend though not significant statistically.

The firmness test was destructive in that tomato fruits did not return to their original size after the first compression. The second compression gave a higher firmness reading

because it now seemed more difficult to compress a very slightly deformed tomato by 5 mm than when it was in its undeformed state. This means that duplicate samples of fruit must be available when testing tomatoes over a number of days as any particular sample can only be compressed once.

These data also suggest that consumers may damage tomatoes when fingering them in the store and stress the need for correct packing of tomatoes to avoid bruising and compression caused by their own weight.

The variation in fruit firmness within a given lot was considerable (Table 5) and the results suggest that it is desirable to test at least twenty-five fruit/12 lb box when the cultivars are mixed, or fifteen when fruit is all of the one cultivar, in order to get a result close to the true firmness value for the lot. The fact that in this experiment only 80% of fruit in a 12 lb lot (average for nineteen lots) was within $\pm 20\%$ of the mean firmness value for the lot (see 'Results') is important when deciding on acceptability levels for tomato fruit firmness at retail level or for use in the home. The panel tests suggested minimum firmness levels of 680 g and 540 g force for retail sale or home use respectively. These values are to be regarded only as pointers.

This system could be used to measure the firmness of a range of fruit and vegetables by using different proving rings and choosing a suitable amount of compression for the particular fruit or vegetable being tested.

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