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FRUIT FIRMNESS MEASUREMENT TECHNIQUES - A NEW APPROACH

C.J. Studman

Department of Agricultural Engineering, Massey University, Palmerston North, New Zealand

A b s t r a c t. The Massey University Twist Tester is a device for testing fruit. It is a possible replacement for the traditional penetrometer. The device measures the moment (torque) required to shear fruit tissue, and this can be converted to an estimate of the crushing strength of the tissue. It is capable of measuring properties as a function of radial depth, and does not require prior specimen preparation, such as peeling the skin from the test area. Typical results of experiments on apples and kiwifruit are presented, including measurements on kiwifruit columella in situ during storage. The output from the Twist Tester was related to the results obtained from conventional penetrometer measurements. The question of whether or not the Twist Tester would be an improvement on the conventional test is discussed, and the basis for making this decision is considered briefly. It is argued that a comparison of standard errors is not an adequate method, and that an alternative statistical method is required. In addition, further refinements of the system are in progress and some of these are also discussed. In particular, new developments are described to remove the operator effect, and to enable the shape of the load-time curve to be established, so that an estimate can be made of the 'bioyield' of the fruit. Examples of the resulting curves are presented. For Granny Smith apples the stored for 130 days Crush Strength values were 490 ±10 kPa, while the Bioyield was 422 ±9 kPa.

K e y w o r d s: fruit firmness, apples, kiwifruit, Twist Tester

INTRODUCTION

The twist tester is a new technique for determining the crush strength of fruit and vegetable tissue *in situ*. It is designed as an alternative to the penetrometer, which has been used as the standard test for firmness measurements for over 60 years, despite well known drawbacks [1,2]. Originally developed by Studman [3], a prototype of the twist tester was described by Studman and Yuwana [4]. The principle is illustrated in Fig. 1, the fruit is pushed onto a blade mounted on a rotatable spindle, so that the blade enters the fruit at a predetermined depth under the skin. The fruit is then rotated, so that the blade turns at the fixed depth, instead of being pushed further into the fruit. A rising weight on an arm resists the rotation. Eventually failure occurs, and the moment (torque) can be calculated from the angle of the arm. The system is fast, simple, does not require the skin of the fruit to be removed, it operates over a greater range, it can be used to investigate changes of properties with depth, it is less messy than the penetrometer (since less juice is exuded during the test), and it damages a smaller area of the fruit, so that additional tests can be conducted. The output is related to strength properties of the tissue immediately in the region of testing. For example, Studman [2] has shown that the crush strength in 'Gala' cultivar apples varies with position, from 690 kPa at the stem end to 810 kPa at the calyx end, and 640 kPa at the equator (cheek). At the equator the tissue strength increased with depth to 840 kPa at

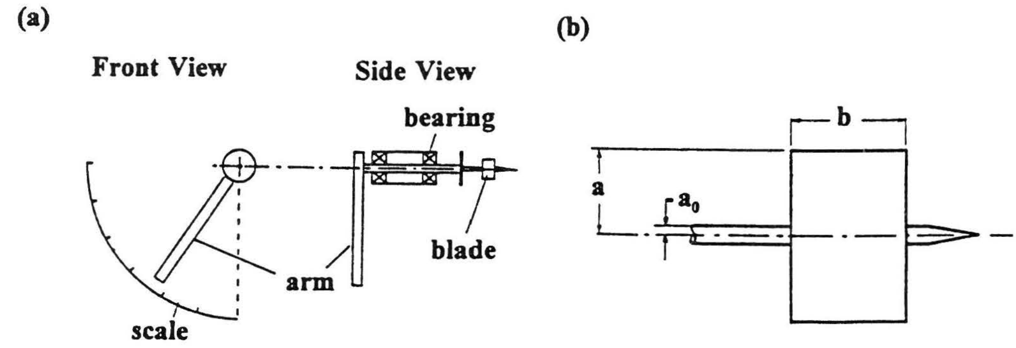

Fig. 1. Principle of operation of Massey Twist Tester. a - general layout, b - enlargement of blade.

18 mm. Its main disadvantages at present are that, like the penetrometer, it is still a destructive test, and as Beaudry has shown, in the form described above, the twist tester output depends on the operator [5]. Another serious problem is that its output is not a familiar term to horticulturalists.

THEORY

As discussed by Studman and Yuwana [7], the maximum moment produced in the test can be interpreted as the moment required to crush the fruit against the blade. The angle at which the fruit flesh failed completely was taken as a measure of the crushing strength. The moment M resisting turning can be estimated by integrating each radial element dx (width b) over the blade. If σ is the crushing strength of the fruit (Pa), a is the radius of the blade (m), a_0 is the radius of the spindle, m is the mass of the arm (kg), Z is the distance of the centre of mass of the rod from the axis of rotation, θ is the angle of rotation (degrees), and g is the gravity constant (9.80 m s^{-2}), then:

$$M=2\int_{a_o}^{a}\sigma x\, b\, dx=\sigma b(a^2-a_o^2)=m\, g\, Z \sin\theta \qquad (1)$$

EXPERIMENTS ON KIWIFRUIT WITH STANDARD MARK 2 TWIST TESTER

A standard Mark 2 Twist Tester was used for the first experiments. The fruit was rotated slowly by hand, so that each measurement took between 4 and 10 s to complete. Samples of 'Hayward' cultivar kiwifruit were tested at intervals over a 200 day storage period. Thirty fruit were used for each test. Each fruit was tested using an 8 mm diameter, 12 kg 'Effigi' penetrometer mounted in a drill press. After 140 days a 4 kg penetrometer was used instead.

Measurements included flesh crush strength at a mean blade depth of 4.2 mm with a blade 6.9 mm in diameter and 4.0 mm wide. The columella crush strength was measured using the same blade inserted from the equator into the centre of the fruit. A 14x4 mm blade was also used for flesh tests.

RESULTS AND DISCUSSION FOR KIWIFRUIT

The results for the two orchards were very similar. The curves followed the process of softening normal for cool-stored kiwifruit, reaching the critical commercial threshold value of 10 N in around 140 days. In Fig. 2 the curves are shown for the fruit from 120 days onwards, with standard error bars shown. Further details are given elsewhere [3].

The results showed that the twist tester can be used to measure crush strength of the kiwifruit tissue and columella throughout the storage life of the fruit. It also showed that throughout the range the standard error in the measurements was comparable with that of the penetrometer. At the critical point in time, when the kiwifruit were approaching the limit of their acceptable storage life, the twist tester continued to produce

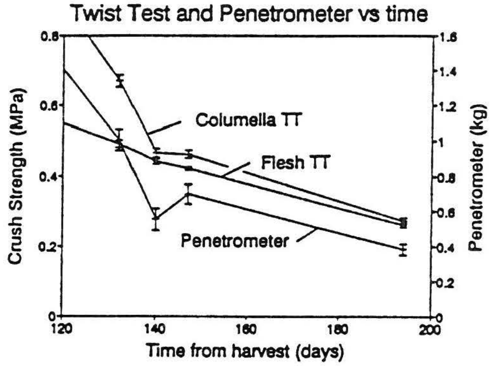

Fig. 2. Crush strength for kiwifruit tissue and columella, and penetrometer values, during storage (Orchard 2).

acceptible results with a small error, while the penetrometer became increasingly less accurate. In Fig. 3 fractional standard errors are shown for each test, showing this deterioration in penetrometer performance. However it is debateable whether a small standard error is a good indicator of the value of a testing device: it could equally be argued that the properties of the fruit within a sample were very different, so that a small standard error indicates that the device is insensitive to changes! An alternative method of assessing new devices is clearly desirable.

MODIFIED TWIST TESTER

Concern about operator and speed of testing effects led to the development of a motor driven Twist Tester (Fig. 4). A second blade of the same size as the first was attached to the output shaft of a low speed gearbox driven at 2 rpm by a small motor aligned on the same axis as the first. The fruit to be tested was pushed fully onto the second blade, and then the motor and fruit were slid on a guide so that the fruit was also pushed onto the first blade, but at a position diametrically opposite to the second blade. As this blade was rotated by the motor, the apple rotated, causing the other blade to rotate, raising the offset weighted arm until the tissue failed. Rotation was recorded with a precision potentiometer mounted on the shaft of the driven blade, connected to a data acquisition system sampling at 70 samples per second. Blade diameters ranging from 5.2 to 18.2 mm at a mean blade depth of 6.0 mm. Thirty Granny Smith apples (size 125, mean weight approximately 148 g) were tested at room temperature after 130 days storage at 1 °C, with three tests per apple.

The values for crush strength were calculated as above. Two alternative measurements were taken from the recorded data.

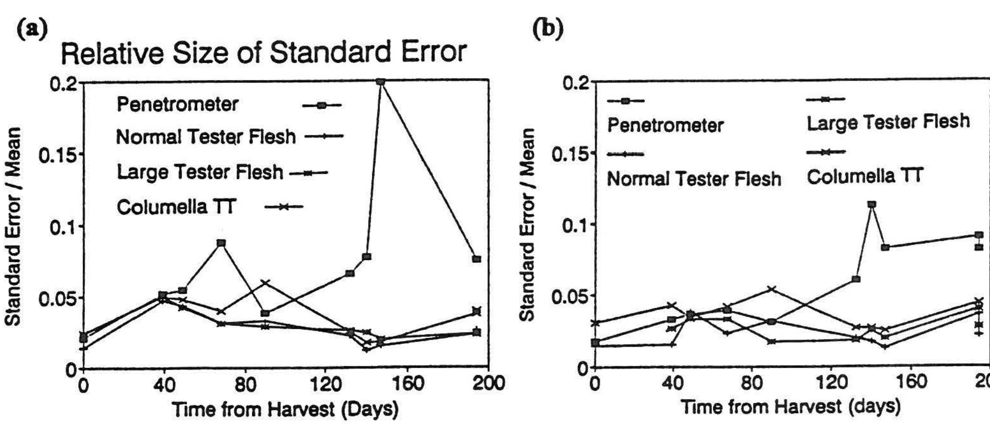

Fig. 3. Relative sizes of standard errors of measurements on kiwifruit from 2 orchards during storage: a - Orchard 1, b - Orchard 2.

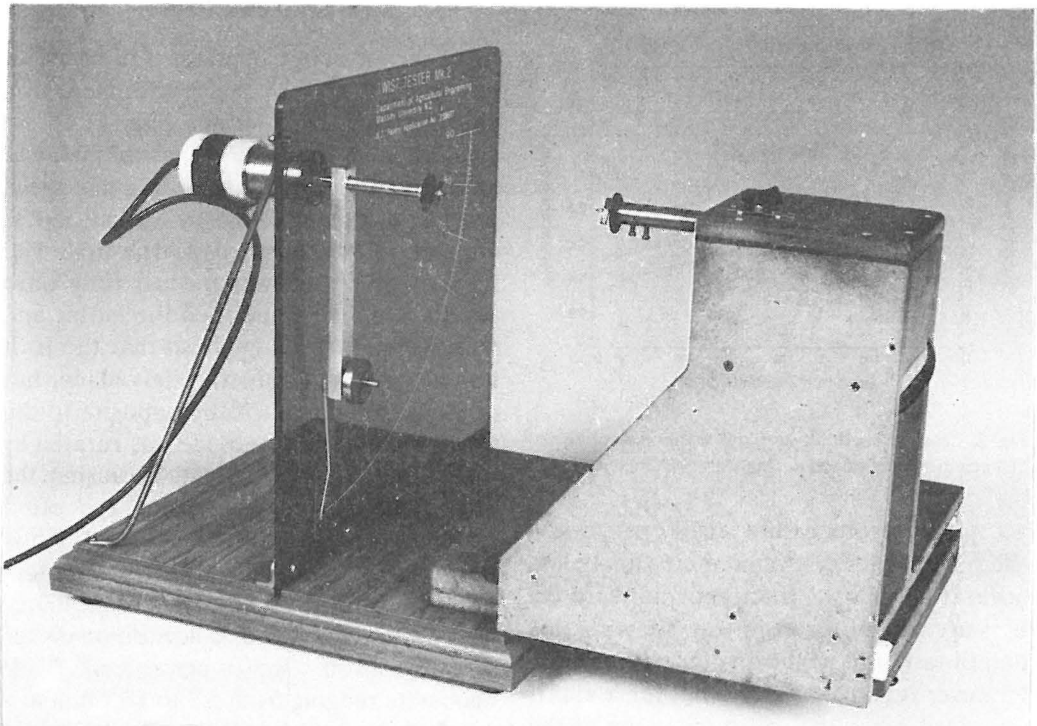

Fig. 4. Motor driven Twist Tester.

The maximum value was the crush strength calculated from the greatest angle recorded, while the apparent 'bioyield' was calculated from the value where the first failure occurred (Fig. 5a-c). Where no obvious failure occurred the apparent bioyield was taken as the point when the blade had rotated 0.11 radian in the apple (Fig. 5d).

RESULTS

Values of shear strength are given in Table 1. Analyses showed that crush strength was not significantly affected by test order. Values calculated using Eq. 1 gave similar results for all blade widths, and diameters. Graphs of angle of twist against time are shown in Fig. 5. In type A (26 % of the tests), the graph rose until it reached an apparent yield point and then continued without further increase in moment. In type B (37 %) the graph rose until it reached an apparent yield, the moment decreased and then increased at a reduced rate. In type C (17 %) the graph rose until it reached an apparent yield point, straightened and then continued to increase at almost the same angle. In type D (20 %) the graph rose until it reached a point where the moment increased at a reduced rate with no specific yield point. There was no significant trend

Table 1. Shear strength and bioyield values for Granny Smith apples after 130 days storage

Blade size (mm)	Crush strength (kPa)		Bioyield (kPa)	
	mean	standard error	mean	standard error
18 x 4	462.9	8.6	414.4	7.8
14 x 4	512.0	10.7	433.4	10.2
5 x 4	501.8	15.0	419.4	8.5

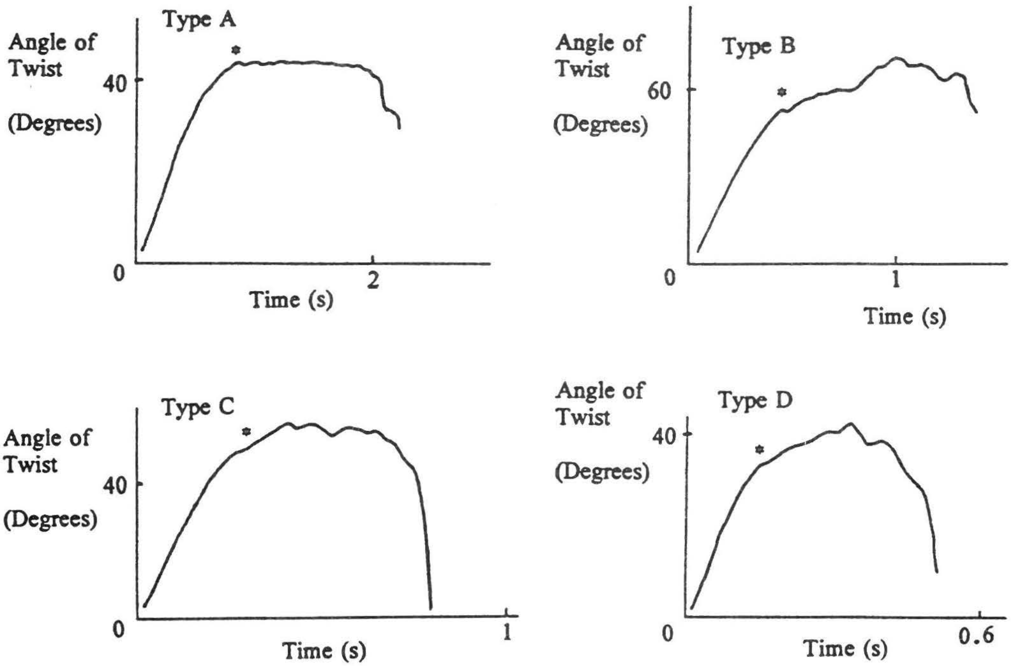

Fig. 5. Angle time curves for motorised twist tester. The bioyield point is indicated by *. Type A - bioyield equal to maximum torque; Type B - torque falls then increases after bioyield; Type C - torque constant then increases after bioyield; Type D - no clear bioyield; value calculated from rotation (see text).

indicating that the type of curve was affected by blade shape or speed. Bioyield values are also shown in Table 1. On some occasions the peak load was unusually high compared to the bioyield. This occurred only with larger radius blades. A study of the fruit showed that after initial failure the blade had struck a green vascular fibre near the outer edge of the blade. These values were excluded from the analysis. The speed at which the fruit rotated on the blade affected the crush strength. There was an 8 % increase in crush strength between 1 and 2 rpm, and a further 8 % increase between 2 and 8 rpm [6].

ANALYSIS AND DISCUSSION

Studman and Yuwana [4] recommended the use of the maximum moment as the criteria for determining crushing strength. However, the increase in load as a result of contact of the blade with a vascular fibre after general failure places this measure in doubt. It is therefore more appropriate to select a different point, and move towards the bioyield concept, following the principles enunciated by Mohsenin [3]. The apparent bioyield may be defined as the point where initial cell failure occurred. This may be found by plotting the angle of twist against time and determining when the blade has rotated a set amount inside the fruit.

CONCLUSIONS

The Massey Twist Tester has been used successfully to measure the tissue strength of apples, kiwifruit, and kiwifruit columella *in situ*. At firmnesses in the 1 kg range, the standard error was much less than that of a penetrometer. The type of graph produced by plotting the angle of twist against time appears to be related to the physical properties of the apple rather than any other variable. Bioyield appears to be a better yield indicator than absolute maximum stress. It is important that speed of rotation be kept as constant as possible.

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