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A new method of firmness measurement of grape berries and other juicy fruits

by

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Eine neue Methode zur Festigkeitsmessung von Traubenbeeren und anderen saftreichen Früchten

Zusammenfassung. — Eine neue Meßtechnik zur Festigkeitsprüfung von Weinbeeren und anderen saftreichen Früchten wird beschrieben. Die Frucht wird zwischen zwei parallelen Flächen durch eine gemessene Kraft deformiert. Das Maß für die Festigkeit ist die Kraft, durch welche eine bestimmte Abplattungsfläche erzeugt wird. Die Apparatur zur Messung der Kraft und Fläche wird beschrieben, und Meßergebnisse an Weinbeeren werden mitgeteilt. Die Messungen sind schnell, einfach und genau, und die Apparatur ist nicht kostspielig. Die Prüfung zerstört die Beere nicht und kann an derselben Frucht mehrmals wiederholt werden.

Introduction

Firmness is one of the main indicators in judging the quality of grapes for consumption. A firm grape signifies freshness to the customer. Grapes lose their firmness by loss of water and/or by changes in their structure. The fruit softens as the time between harvest and marketing increases. Sometimes, the grapes may have been already soft at harvest because of faulty water regime or chemical treatments (such as Ethephon) used to achieve earlier ripening or colour. Great efforts have been made to market firm grapes by treatments in the vineyard, by proper cold storage and by special means of transport and packing. Firmness measurement is a valuable tool to discriminate the characteristics of various cultivars; particularly regarding shipping quality and customer acceptance.

Instrumentation for firmness testing in grapes imitates the sensory firmness test of compressing the fruit between the forefinger and thumb, or between the molar teeth (Peacock *et al.* 1978).

Most measuring devices are based on one of the following principles:

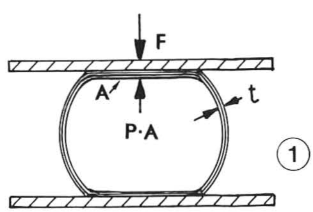
a) Measurement of the deformation which results from the application of a fixed force.
b) Measurement of the force which is required to obtain a predetermined deformation.

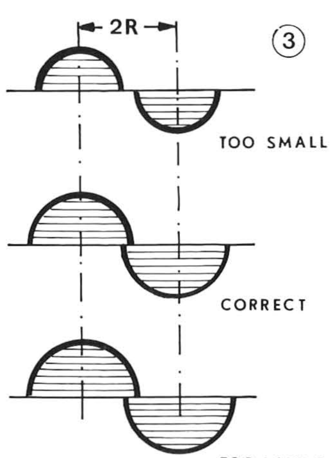
Hale *et al.* (1970) measured ripening of grapes by compressing them between the jaws of spring loaded calipers with given tensions. Bourne (1966, 1973, 1980) describes a number of instruments which are used for non-destructive firmness tests and which are based on deformation measurements. They include the much used „Penetrometer“ and the automatic "INSTRON" strength of materials testing machine.

All these devices measure the relation between the applied force and the linear displacement of an indentor. It can be shown that this method, when applied to juicy fruits, is influenced by the size of the fruit, so that variations of firmness in a single batch are to be expected. Most of these tests are relatively time consuming and readings taken in different measuring ranges cannot be easily related.

The need for an improved instrument for firmness testing has therefore arisen and the one described here allows the execution of non-destructive tests, which are independent of size variations in fruit. It may be used in repeated experiments on the same sample (water regime tests etc.) and tests in different ranges can be related without any difficulty. The extremely short duration of the test allows the use of statistically large samples.

The method is based on the dependence of the firmness on the turgor pressure (NILSSON and HERTZ 1958) and, in principle, is of hydrostatic nature. Small deformations are applied as they give results which are less dependent on the inner structure of the fruit (HAMANN and DIEHL 1978) and allow a better discrimination between samples (BOURNE 1980).





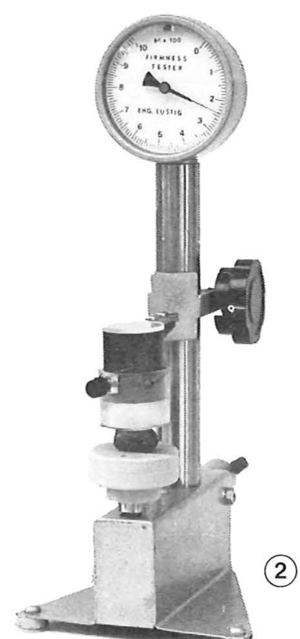


Fig. 1: Forces at balance. — Fig. 2: View of the tester. — Fig. 3: Image of the pattern.

Abb. 1: Kräfte im Gleichgewicht. — Abb. 2: Ansicht des Prüfgerätes. — Abb. 3: Abbildung der Abplattung.

Theory

The berry is regarded as a liquid-filled, spherical vessel of radius R, as first approximation (Considine *et al.* 1974). It has a thin, elastic skin of thickness t. Its firmness is determined by the turgor pressure P_T. In order to imitate the sensory compression test, the fruit is deformed between two parallel surfaces by the application of a variable force F which is at right angles to them. This results in the applanation area A (Fig. 1). At static conditions, force F balances the action of the increased internal pressure of the fruit P on the area A.

The internal pressure P will now be the sum of the turgor pressure and the additional pressure P_D caused by the deformation and the additional skin stress.

$P = P_T + P_D$ (1)

At balance, the applied force will be equal the internal pressure times the applanation area.

$F = A \cdot P$ (2)

For a given area the applied force is therefore directly proportional to the internal pressure. Further development of these expressions, applying standard theory of thin walled pressure vessels and by assuming small deflections (Timoshenko 1949) leads to the following result:

$$F = A \cdot P_T + \frac{E \cdot t}{R^3} \cdot \frac{A^3}{\pi A + 2\pi^2 R^2} \quad (3), \text{ where}$$

F = Applied force
A = Applanation area
P_T = Turgor pressure
E = Young's modulus of the skin
t = Mean skin thickness
R = Mean radius of the berry

The first term of this expression is directly proportional to the turgor pressure and therefore expresses the firmness of the fruit. The second term represents the component of the force due to the skin tension.

Although this treatment is strictly true only within the limitations stated above, it has been found that it may be successfully applied to the measurement of firmness. The force necessary to create a given applanation area is used as firmness index.

Method

In an instrument based on this theory the fruit is compressed between two large sized parallel plates. To make it possible to observe and measure the applanation area which appears during the deformation, the upper plane is made of a transparent material and carries means for the determination of this area (the pattern). For constructional reasons it was decided to use a fixed, predetermined area and a variable force. In a spherical berry the pattern has a circular form. In other fruits its form is an ellipse with an aspect ratio similar to that of the fruit. The force per unit applanation area is a measure of the internal pressure of the deformed fruit. At small deformations there is a quasi-linear relationship between the area and the applied force. Such small deformations will not cause skin stresses which exceed the elastic limit, so that repeated measurements are possible. Loss of definition of the pattern boundary due to surface roughness of the fruit limits the lower pattern size. In berries of grapes an area of 0.4—0.6 cm^2 was suitable.

A simple apparatus (Fig. 2) for routine measurements of firmness for laboratory and field use has been developed. It consists of two parallel plates, the distance of which can be adjusted to the diameter of the fruit. The lower plate is part of the force measuring device, while the upper is mounted on a carriage and may be lowered by a hand drive. The force is measured by a spring balance of 1 kp[1]) range, which forms the base of the apparatus. Downward movement of the upper plate applies the force. The upper plate is transparent and carries the area measuring device.

In an earlier prototype, a simple glass plate with a marking of the selected pattern of the given area was used. The glass plate was lowered until the pattern filled the marking and then the force reading was taken.

In the present apparatus, a more elaborate optical device is used for the measurement of the pattern size. It consists of a prismatic image splitter (BECKER and SHAFFER 1963) which divides the pattern into two halves and displaces them by one diameter of the desired circle along the division line. When the pattern reaches the size of the circle of the desired area, the two halves will be at a tangent to each other (Fig. 3). This display is easy to read and very accurate. The amount of displacement can be adjusted by a knob, so that different areas can be measured. In the case of an elliptical pattern the division line is adjusted so that it coincides with the short axis of the ellipse. The necessary amount displacement for a given area is calculated from the aspect ratio of the ellipse by the use of a simple formula. The aspect ratio in this case is the ratio of the long to the short axis of the pattern. Calibration is carried out by means of the displacement adjustment and a linear scale.

In practice it was found that the definition of the pattern can be enhanced by the application of a drop of coloured liquid to the fruit just before compression. This will create a coloured rim around the pattern which facilitates the recognition of its limits and eliminates reading errors due to capillarity. For best contrast the colour has to be light for dark fruit and vice versa.

Results and discussion

Differences in firmness can be easily recognized with the instrumentation described above. The force necessary to create a given pattern in a hard cultivar may be five times as large as that in a soft one. For instance, a soft cultivar, such a Muscat Hamburg, will require a force of about 100—200 p to create a pattern of 0.6 cm^2, while a hard cultivar, such as Barlika or Verigo, will reach the same area at 500—700 p. Cultivars which have small berries (less than 3 g) should be tested at areas less than 0.6 cm^2 to avoid non-reversible strains in the skin.

Water losses from the berry to the atmosphere or to the plant result in a decrease of the turgor pressure and, consequently, of firmness. The relationship between firmness and water condition is evident from Fig. 4 which shows the weight of the berries at a given time and the force necessary to attain a pattern of 0.6 cm^2,

[1]) For practical reasons, in this paper "kp" and "p" are used as force units instead of the SI unit "N".

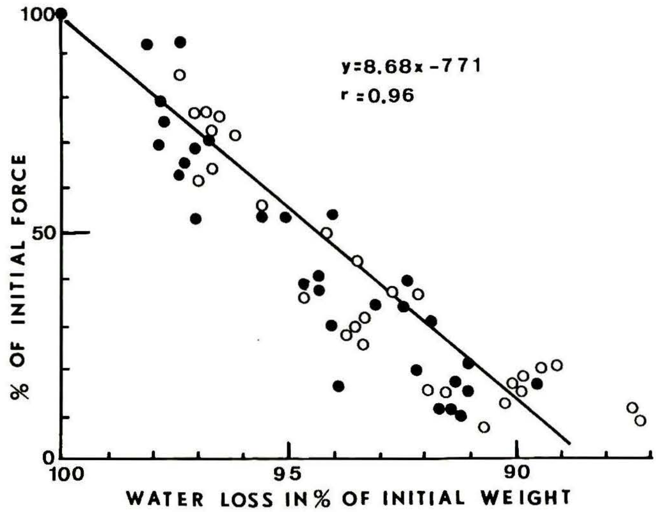


Fig. 4: Relation between water loss and firmness in Dattier grapes. ○ = In the open air, ● = in an airconditioned room. Mean values of 10 berries in each series.

Beziehung zwischen Wasserverlust und Festigkeit bei Trauben der Sorte Dattier. ○ = Im Freien, ● = in einem klimatisierten Raum. Mittelwerte aus 10 Beeren in jeder Serie.

both as percentage of the initial, maximal values. Prior to the test, the berries had been brought to their maximal firmness by immersion in distilled water. Water loss was brought about by their exposure to atmosphere in an air conditioned room and, alternatively, to the open air in the shade. The results show that this method is a sensitive indicator of water condition in grapes for commercial applications and in research in fields such as irrigation, packing, storage and transport. For example, firmness measurements on the Cardinal cultivar in a well irrigated vineyard showed changes in firmness values from 450 p at 0.6 cm^2 in the morning to 350 p at the same area in the evening.

Measurements of firmness, carried out at different applanation areas, can be meaningfully converted without difficulty as can be seen in Fig. 5 which shows a practically linear relationship between the applied force (as firmness index) and the pattern area at small applanations (0.4—1.0 cm^2).

One of the advantages of the force versus applanation area method of firmness testing is its practical independance on variations of berry diameter. If berries of the same turgor pressure and, consequently, of the same firmness are tested by this method and compressed to a given applanation area, the force reading will be the same in each test. Geometric considerations will show, however, that a test conducted on the same batch by the force versus deflection method will give different results. If the berries are compressed to the same depth, different applanation areas are created so that a larger force is required in the larger berry and a higher firmness will be indicated. This discrepancy is apt to grow as the compression is increased.

In a test carried out on grape berries of different sizes, arbitrarily collected from the same bunches, it was found that there were no significant variations of the measured firmness values (Table).

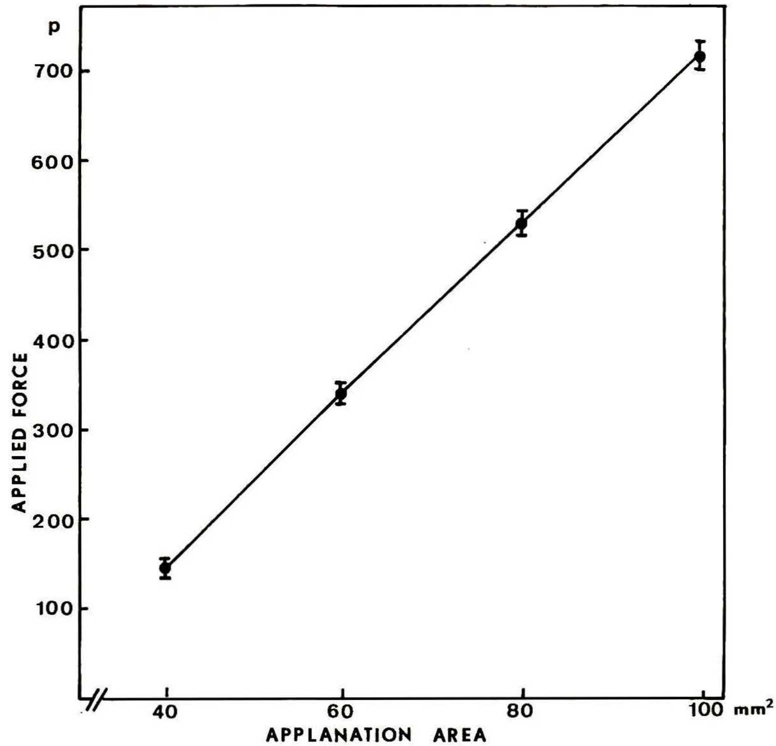


Fig. 5: Pattern area (mm²) versus applied force (p) in Dattier grapes (mean values of 50 berries).

Abplattungsfläche (mm²) in Beziehung zur angewandten Kraft (p) bei Trauben der Sorte Dattier (Mittelwerte aus 50 Beeren).

Force in p to produce a given applanation area in berries of various sizes of one bunch of Dattier grapes (mean values of 16 berries)

Kraft in p, die zur Erzeugung einer bestimmten Abplattungsfläche an Beeren unterschiedlicher Größe einer Traube der Sorte Dattier erforderlich ist (Mittelwerte aus je 16 Beeren)

Small berries < 6 g	Medium berries 6—7 g	Large berries > 7 g	Area cm²
145	150	150	0.4
343	354	337	0.6
528	546	515	0.8
715	716	696	1.0

In analysing the relationship between the applied force and the turgor pressure (equation 3) it can be seen that the second term of the right hand side of the equation decreases rapidly as the applanation area decreases. Measurements on grape berries of a mean radius of 1 cm have shown that the contribution of the second term to the total force was about 7 % at an applanation area of 0.6 cm² and about 5 %

at an area of 0.4 cm². This shows that variations in size and skin strength have little effect on the measured results as long as a small applanation area is used.

Summary

A new method of firmness measurement of grape berries and other juicy fruits is described. The fruit is deformed between two parallel planes by a measured force. The measure for the firmness is the force which generates a given applanation area. Apparatus for measurement of the force and the area is described and measurements on grape berries are given. The measurements are fast, simple and accurate and the apparatus is inexpensive. The test is non-destructive and may be repeated several times on the same fruit.

Literature cited

BECKER, B. and SHAFFER, R., 1963: Diagnosis and therapy of the glaucomas. C. V. Mosby & Co., St. Louis. U.S.A.

BOURNE, M. C., 1966: A classification of objective methods for measuring texture and consistancy of foods. J. Food. Sci. 31, 1011—1015.

— — , 1973: A research note: Use of the Penetrometer for deformation testing of foods. J. Food Sci. 38, 720—721.

— — , 1980: Texture evaluation of horticultural crops. HortScience 15, 51—57.

CONSIDINE, J. A., WILLIAMS, J. F. and BROWN, K. C., 1974: A model of stress in dermal tissues of mature fruit of *Vitis vinifera;* criteria for producing fruit resistant to cracking. Mechanisms of regulation of plant growth. Bull. 12. Roy. Soc. New Zealand, Wellington, 611—617.

HALE, C. R., COOMBE, B. G. and HAWKER, J. S., 1970: Effects of ethylene and 2-chloroethylphosphonic acid on the ripening of grapes. Plant Physiol. 45, 620—623.

HAMANN, D. D. and DIEHL, K. C., 1978: Rheology of soft fleshy fruit. Food Technol. 32 (7), 57—61.

NILSSON, S. B., HERTZ, C. H. and FALK, S., 1958: On the relation between turgor pressures and tissue rigidity. II. Physiol. Plant. 11, 818—837.

PEACOCK, W. L., JENSON, F. L. and ELSE, J. A., 1978: Testing Ethephon treated table grapes for berry firmness. Calif. Agricult. 32, 4—8.

TIMOSHENKO, S., 1949: Strength of materials. II, 159—160. Van Nostrand, New York.

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