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A Field Instrument for Testing Firmness of Citrus Fruit[1]

G. Felsenstein and D. Nahir[2]
Institute of Agricultural Engineering, Agricultural Research Organization, The Volcani Center, Bet-Dagan, Israel

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Abstract. **An instrument for in-the-field testing of citrus fruit firmness has been developed and tested. Linear deformation of a fruit along its diameter under the pressure of a constant force was found a good criterion of weight loss, and hence firmness of citrus.**

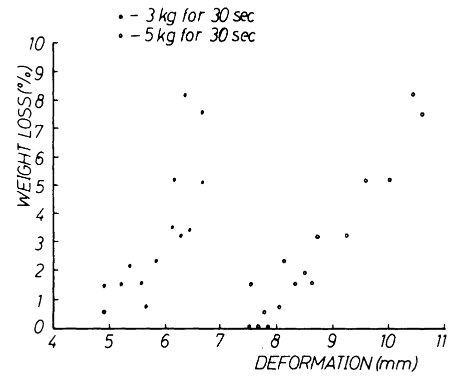

Fig. 1. The relationship between weight loss and diameter deformation under two loads, 30 sec after application.

Mechanical forces to which citrus fruit are exposed during handling, transportation and storage may be detrimental to their quality. The advent of additional mechanization during harvesting and packing has agravated this problem. There is an increasing need for suitable methods and instruments for measurement of a relevant physical property, such as firmness which will indicate the current condition of the fruit and enable prediction of its future ability to absorb more energy or to store well. These tests may be carried out in the packinghouse, during storage and at the marketing stage, to determine relative quality of fruit in regard to its firmness.

Sarig and Nahir (6) proposed an objective and replicable method for rapid testing of fruit firmness, as a substitute of the well known "thumb-test." This method is based on Lissner's approach that biological materials can be considered as regular engineering materials in respect to their mechanical properties (2).

Many significant results have been obtained in the past 10 years on the relationship between physiological properties of fruits and vegetables and some of their physical properties (3, 4, 5). Sarig and Orlovsky (7) found during an investigation of rheological properties of citrus fruit that it can be considered as a visoelastic material, which makes its behaviour predictable, under applied force.

Ben-Yehoshua (1) and D. Nahir (unpublished data) found a good correlation between weight loss of oranges and lemons, and their firmness, as expressed by linear deformation under a constant load.

The present work had 2 main objectives: to establish simple loading parameters in order to cause measurable compression of tested fruit and to develop an instrument for prompt measurement of fruit deformation under a predetermined constant load.

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Residual (permanent) deformation, which is typical for a fruit under stress when tightly packed in a container, was found to be almost identical to the value of its initial deformation when a certain force is applied for a short period of time, 5 kg for 15 to 30 seconds in the case of oranges and grapefruit (6).

Initial tests were made with a load cell and a linear velocity desplacement transducer (LVDT) set-up used by Sarig (7). Loading conditions and recording were highly controllable and accurate to 1/100 of 1 mm, but this procedure was not suitable for field use. Export-grade oranges, waxed and packed in fiberboard containers were numbered and stored at 22–25°C and 65–80% relative humidity. Weight loss was determined by weighing each orange twice a week. A sample of 10 fruits was tested for firmness once a week and discarded. Tests with the field instrument were run in the same way with 'Valencia' and 'Shamouti' oranges during 2 seasons, in order to determine the required force to be applied during the testing procedure, and the time period after which the initial deformation will be recorded. These tests were based on the previous work mentioned above, in which a good relationship between weight loss and firmness was established.

A typical graph representing the initial deformation after 30 sec under loads of 5 kg and 3 kg, for count 90, 76–81 mm diam. 'Shamouti' oranges is shown in Fig. 1. The slope of the 5 kg curve is smaller than that of the 3 kg one, so it will be easier to determine fruit firmness by loading it with the higher force. Forces exceeding 5 kg may cause flesh and rind breakdown in some cases, thus affecting the measurement. It was also found that the initial deformation under a load of 5 kg can be measured only 15 sec after the application of force. The main deformation occurs immediately with application of the load, and only slow creeping takes place after that (Fig. 2).

The design of the field instrument was based on 2 main requirements, ease of operation and reliability of readings. A coiled spring is used to apply the load and deformation is measured by a dial indicator, in order to simplify the field use (Fig. 3). The sample to be tested, no. 1 in Fig. 3, is placed between two parallel plates, no. 2 and 3. One plate no. 2 is fixed in position with a set screw no. 4, while the other no. 3 rests against the dial indicator push rod no. 5. The indicator no. 6 is adjusted to read zero displacement. The load is applied by pulling a lever no. 7 against a grip handle no. 8, until it reaches a stop no. 9. The lever compresses the coiled spring no. 10, which applies the required force through a simple sliding mechanism to the movable plate no. 3. Displacement of the movable plate is read on the indicator dial, after a period of about 15 sec with an accuracy of 0.02 mm. The stop no. 9 can be adjusted in order to achieve various loads from 2.5 to 6 kg in the present instrument.

Field tests. 'Valencia' oranges of various sizes were tested during the 1974/75 season for firmness during

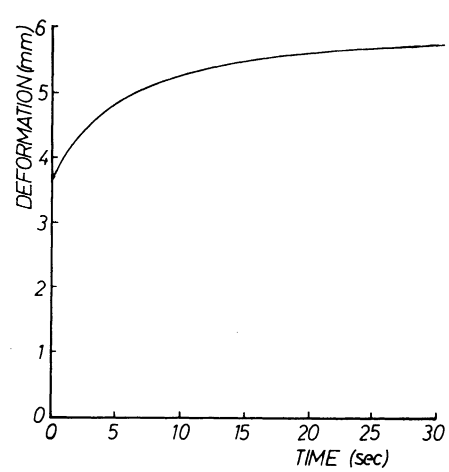

Fig. 2. Typical time-deformation curve for 'Valencia' oranges under a load of 5 kg. (Note that after 15 sec, deformation increased only by 0.25 mm, i.e. less than 5%.)

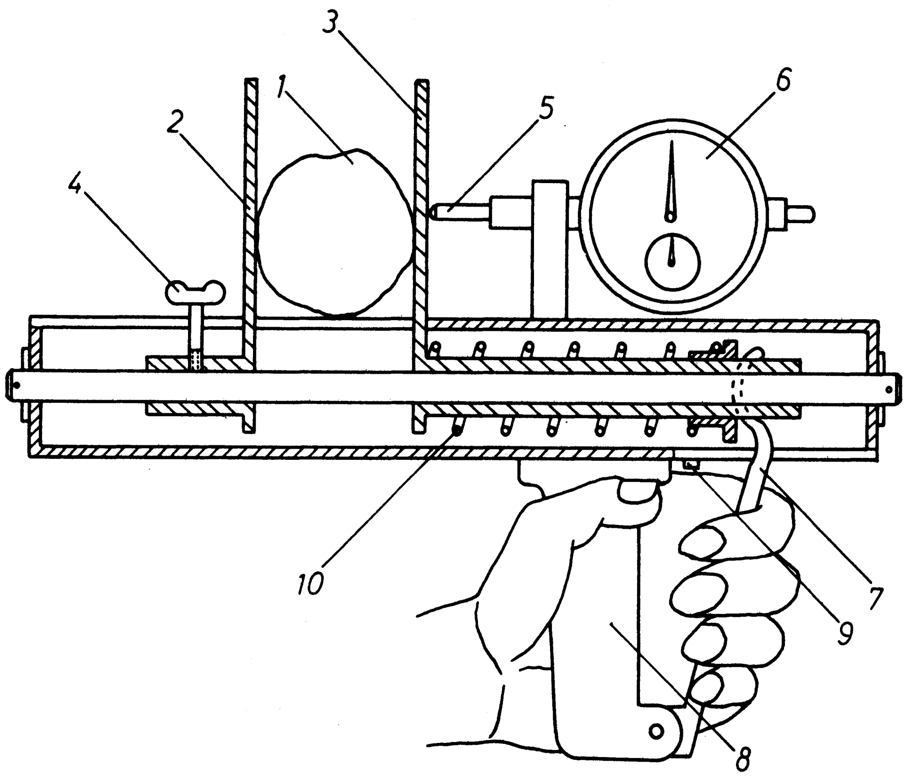

Fig. 3. Schematic diagram of the instrument for measuring firmness of citrus fruit (patent pending).

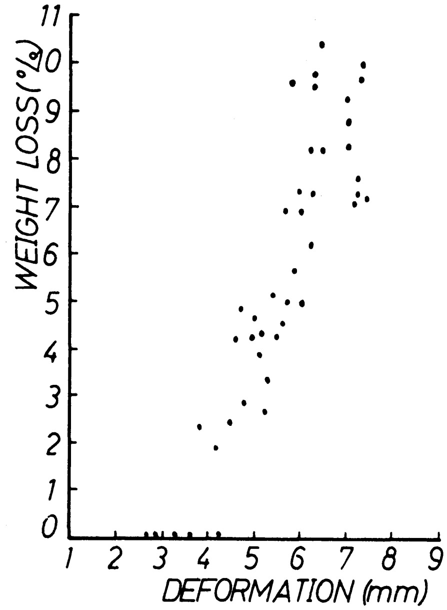

Fig. 4. Weight loss vs. diameter deformation for 75 count 'Valencia'.

storage with the field instrument and readings were related to their weight loss. Typical results are shown in Fig. 4. Each point on the graph represents the mean value of 10 fruits. No differences in deformation were detected between fruits of close counts, which had a similar loss in weight. This can be explained by the fact that the area on a fruit which contacts the pressure plate (no. 3 in Fig. 3) increases as the fruit's diam increases. Thus the stress (stress= force/area) in a large fruit is smaller than in a small one under the same force. It was found that 'Valencia' oranges of counts 75 and 88 have a similar weight loss-deformation characteristic and those of counts 105 and 123 have also a similar curve. This can be seen by comparing B and A parameters in Table 1.

It may be assumed that the relationship between deformation (firmness) and weight loss is linear up to a value of 11–12% weight loss, as it has been measured in the present work. The range above this value of weight loss is not relevant to commercial applications, since shrivelling renders the fruit unmarketable.

Statistical analysis. Regression analysis has been done to find the parameters of the weight loss vs. deformation curves. It was found that a linear formula of the $y = Bx+A$ type (where y = weight loss and x = initial deformation), gave the best results (Table 1). In all cases all non-linear correlation-factors were lower than those of linear correlation, up to the measured value of 12% weight loss.

A series of 5 instruments is now under construction for use in further field experiments. More research is needed to find deformation ranges which will indicate the firmness of various fruits and sizes. The next generation of this instrument may not show deformation in mm, but will have several scales specific for various fruits, such as oranges, grapefruit, cantaloupes, peaches, strawberries, tomatoes etc., on which the fruit firmness will be indicated on an arbitrary scale. Also, more research should be done to evaluate the meaning of changes in firmness and their influence on the storage of the fruit.

Table 1. Parameters of the curves $y=Bx+A$ for Shamouti and Valencia oranges of various counts. (y=weight loss; x=deformation)

Cultivar and count	Applied force and time	B	A	Coeficient of correlation
Shamouti 90	3 kg 30 sec	3.111	−14.79	0.793
Shamouti 90	5 kg 30 sec	3.426	−18.33	0.958
Valencia 75	5 kg 15 sec	2.164a	−6.59	0.882
Valencia 88	5 kg 15 sec	2.785a	−4.41	0.854
Valencia 105	5 kg 15 sec	3.103b	−11.48	0.828
Valencia 123	5 kg 15 sec	2.970b	−12.69	0.994

a, b – Significant difference at 5% level.

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