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# COMPARISON BETWEEN ACOUSTIC RESPONSE AND LOW MASS IMPACT MEASUREMENT TECHNIQUES TO ASSESS AVOCADO FIRMNESS

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## SUMMARY

Two non-destructive dynamic test methods, low-mass impact and acoustic response, were tested and compared with destructive compression and penetration tests to evaluate avocado ("Fuerte" cultivar) firmness. The purpose of the study was to analyse the performance of the impact test methods for non-destructive firmness evaluation. A bench top low-mass impact firmness tester produced by Sinclair International (SIQ-FT) was used to perform the impact tests, and a piezoelectric-film transducer was applied in the acoustic tests. The Sinclair internal quality index (IQ) and a firmness index (FI) were calculated from the output signals. The non-destructive tests were followed by parallel-plate compression and cone penetration tests. The SIQ-FT can capably detect the ripening stages of avocados. The correlation between the destructive tests was high (R=0.943) as was that between the low-mass impact firmness (SIQ-FT) and modulus of elasticity and cone penetration (R=0.953 and R=0.955, respectively). The correlations of the acoustic technique (FI) to the elastic modulus and cone penetration, were lower (R=0.68 and R=0.695, respectively). The findings demonstrated the advantage of measuring non-spherical fruit by a low-mass impact technique compared to the acoustic technique, and the potential of using the SIQ-FT to assess fruit quality non-destructively.

**Key Words:** non-destructive, impact, acoustic, firmness, avocado, quality.

## INTRODUCTION

Fruits and vegetables need to be high quality in today's trade market. Each fruit needs to be graded for quality, and be ripe and ready to meet marketing and advertising standards. Fruit needs to be sorted not only by weight and colour, but also for texture. Texture is one of several qualitative terms used to describe fruit quality and is most important for sensitive fruits, like avocados, whose shelf life is very limited after reaching a certain level or stage of ripening. Developing a reliable testing method that will measure each individual fruit will enable suppliers, distributors and repackers to optimize fruit treatment, storage and shipment management to reduce processing cost and minimize fruit loss and wastage.

Destructive measurements of fruit flesh penetration, after removing the skin, using an 8 mm diameter cylinder is known as the Magness-Taylor (MT) test, is often used in industry to evaluate texture quality in fruit such as apples, pears, stonefruit and avocado. Some fruits and vegetables, especially those that have a short shelf life such as avocados, do not yet have a standard method for evaluating their internal properties. Some avocado industries adopted the destructive test (MT), which is very time consuming and increases loss of fruit and measures the statistical average and not each individual fruit. Therefore, a continuous effort is being made by the scientific community to develop new nondestructive methods for fast texture evaluation of each individual fruit.

After a mechanical impulse, the analysis of the acoustic response produced in the frequency domain can yield the properties, such as firmness, of the whole fruit. Low-mass impact analysis in the time domain is another method for determination of fruit properties. The motivation of the present work is to compare two fast nondestructive methods for firmness testing of avocados.

### Quality Detection by Impact Force

Numerous researchers have reported on the evaluation of fruit firmness using impact techniques. These techniques include dropping the fruit on a transducer (DeBaerdemaeker et al., 1982; Delwiche, 1987) and using low-mass devices to apply impact on the fruit (Chen and Tjan, 1998; Delwiche and Sarig, 1991). Recently, Sinclair International Ltd. modified their fruit labelling bellow machine so that it can measure firmness using a sensing element on the tip of the bellow. The sensor measures the fruit response to low impact using a force transducer. The firmness is determined by an index extracted from the force-deformation impact curve over a period of time (Shmulevich et al. 2003). In general, the researchers reported good correlation between the impact indices and the results from common destructive tests (MT and compression) in apples. The advantages of the impact method are its non-destructive nature, simplicity and speed. The main disadvantage of this technique is that it measures a local phenomenon. This disadvantage can be overcome by measuring the fruit in different locations.

### Quality Detection by Acoustic Techniques

An alternative method for evaluating texture quality via frequency response was suggested by Yamamoto et al. (1980). In several studies the acoustic emission was sensed by using a microphone, an accelerometer or by flexible piezoelectric sensors, and the signal was analysed using a fast fourier transform (FFT) algorithm to extract the fruit's resonant frequencies. Shmulevich et al. (1996), Galili et al. (1998), and Galili and DeBaerdemaeker (1996) used a similar approach.

The acoustic response in several fruits, such as mango, melon, avocado and apple, was examined by several groups of researchers and yielded good results for firmness and ripening prediction.

However, the limitation of this method is the need to orient the fruit and the sensitivity of the measurements to the fruit shape.

The general objective of this research is to compare two non-destructive sensing techniques for firmness measurement, by demonstrating their performance in testing avocados ("Fuerte" cultivar).

## METHOD AND MATERIALS

The experiment included 150 avocados ("Fuerte" cultivar) which were brought from the orchard fields and kept in laboratory conditions of about 24 ºC and 50% relative humidity. The avocados were measured over 7 days. The destructive tests included 10 fruits every day. The two non-destructive tests were performed daily. Also, the weight, axial length, maximum diameter and radii of curvature of each fruit were measured as well (Table 1).

The experimental set-up included two non-destructive systems that were designed to detect firmness by measuring the fruit response to low-mass impact and by using an acoustic techniques. Testing included:

1. A Sinclair IQ™ - Firmness Tester (SIQ-FT), which was used for impact measurements (Fig. 1). The SIQ-FT is based on a sensing element held inside the tip of the Sinclair bellow expander which measures the impact response of the fruit. A special data acquisition and signal analysis program (by Sinclair) was employed to determine the IQ (Shmulevich et al., 2003). The air pressure setup of the machine was 15 cm $H_2O$, and the sensor height above the fruit was 15 to 35 mm for most fruits, depending on fruit size. Typical input signals in the time domain of the Low-Mass Impact system by Sinclair for different fruit conditions are shown in Fig. 2.

2. The Piezoelectric-film sensor system Firmalon™ by Eshet Eilon Ltd. (Fig. 3) was used to measure the fruits' acoustic response. The system includes a force transducer to detect the fruits' mass, a fruit-bed equipped with a piezoelectric sensor bonded to soft polyethylene-foam padding (which enables free vibrations of the fruit), and an electro-mechanical impulse hammer. A data acquisition computer program (Test-Point™) was used to control the test operations, to select the resonant frequencies and to calculate the acoustic parameters of the fruit. The Acoustic Firmness Index (FI) was calculated by using the term ($F_1^2\ m^{2/3)}/10^6$), where $F_1$ = the natural frequency and m = fruit mass. The average of four tests per fruit was calculated. A typical signal in the time and frequency domains is shown in Fig. 4.

In addition, an Instron™ 4204-Universal Testing Machine performed a parallel plates compression test in order to determine the apparent elastic modulus (E) of the fruits according to the ASAE 368.3 standard. The maximum displacement was 5 mm in all tests. The test was conducted at constant head velocity of 50 mm/min. Two compression tests were carried out in perpendicular directions. Radii of curvature were measured near the loading points. The force deformation curve was analysed. The average of two tests per fruit were calculated and compared with the other tests.

The strength of the fruit tissue was determined by means of a $60^0$ conical indentor plunger, 6.35 mm at maximum diameter. The maximum force (MTC) required to penetrate 10 mm into the tissue through the fruit peel was recorded. Two penetrations on 2 different sides of the fruit were performed.

## RESULTS AND DISCUSSION

The data obtained from the three non-destructive systems was correlated to the destructive methods using the Pearson linear correlation. The results are presented in Table 2 and the values are significant at the 0.05 level.

The 150 avocados mass ranged from 168 to 459 g. The test period lasted 7 days at room conditions. A very high correlation was observed between the two destructive methods E and MTC (R=0.943). The impact method correlates much better to the destructive elasticity modulus and to the cone penetration (R=0.953 and 0.955, respectively) than the acoustic system (R=0.689 and R=0.695, respectively). These findings can be explained by the high sensitivity of the acoustic method to fruit shape. In our case the ratio between the fruits axial length to maximum diameter ranged between 1.75 and 2.00 while the theory assumes spheres objects. The relationship between the SIQ-FT and the destructive tests is not linear and changing during the ripening process as demonstrated in Figures 5 and 6. The " S " shape curve is typical to the ripening process. It will be easy to select boundaries for grading avocados into different grades of firmness quality, e.g., hard, soft and medium. Notice that the medium range is spread over 30 IQ units, this will allow segregating fruit to additional levels of firmness. The results demonstrated that the low-mass impact technique can optimize processing and supply management decisions which may reduce fruit losses and control quality by supplying uniform fruit.

## CONCLUSIONS

Two non-destructive systems for assessing fruit texture were used to measure avocado firmness. Quality indices were obtained from the output signals of each system and compared to destructive tests. The main conclusions from this research can be summarized as follows:

The elastic modulus, which is the physical measurement of firmness, correlated very well with the IQ index for avocados (R = 0.953) but less with the acoustic firmness index FI (R=0.689). The SIQ-FT can detect the firmness stage of avocados if compared to destructive as well as non-destructive tests.

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**Table 1:** Mass and dimensions of the avocados tested.

| | Weight (g) | AL (mm) | D1 (mm) | D2 (mm) |
|---|---|---|---|---|
| Max | 459.2 | 160.0 | 77.7 | 78.1 |
| Min | 167.8 | 102.2 | 57.9 | 58.4 |
| Average | 283.0 | 131.3 | 66.3 | 66.6 |
| S.D. | 46.89 | 10.81 | 3.95 | 3.83 |

**Table 2:** Pearson linear correlation between the destructive and non-destructive tests on avocados.

| | FI | IQ | E | MTC |
|---|---|---|---|---|
| FI | 1 | 0.714 | 0.689 | 0.695 |
| IQ | | 1 | 0.953 | 0.955 |
| E | | | 1 | 0.943 |
| MTC | | | | 1 |

**Figure 1:** The Sinclair IQ$^{TM}$ –FT low-impact testing apparatus.

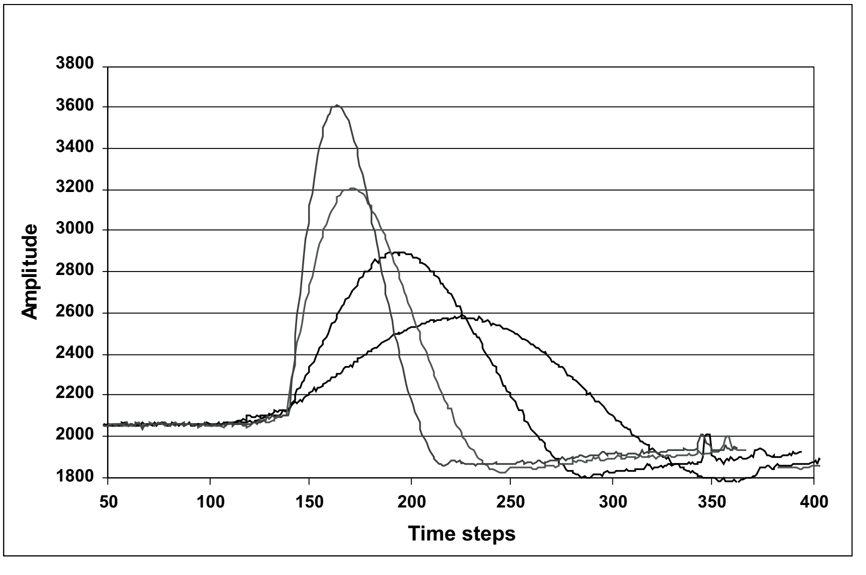


**Figure 2:** Typical input signals in time domain of the Low-Mass Impact system by Sinclair for different fruit conditions.

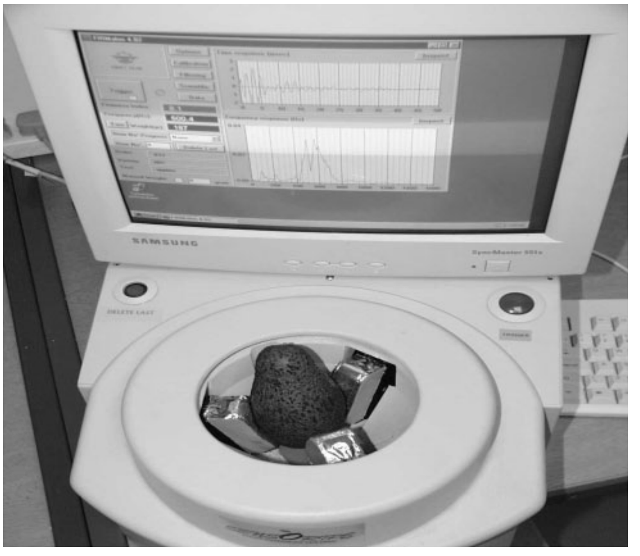

Figure 3: The Technion acoustic test apparatus "Firmalon".

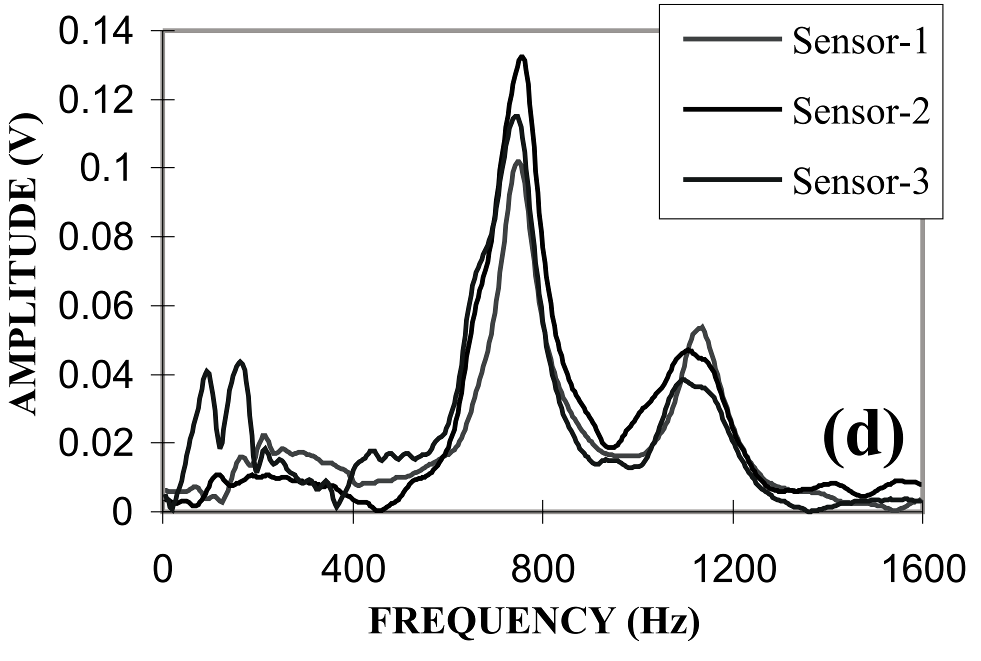


Figure 4: A typical acoustic signal in the frequency domain.

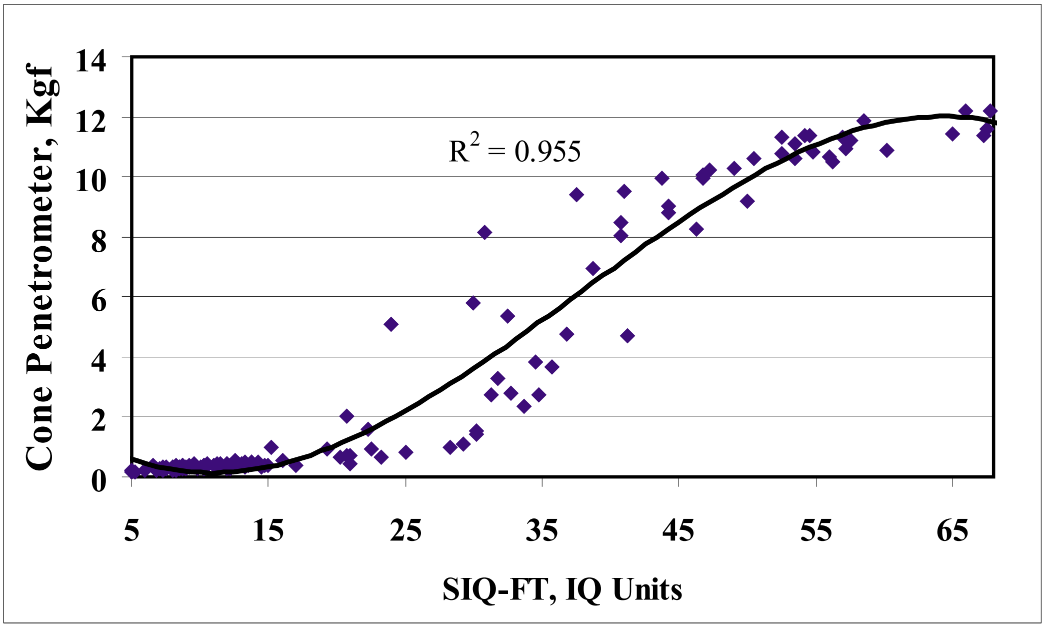


**Figure 5:** Firmness measured by SIQ-FT in IQ units vs. Cone Penetration measurements in Kgf for 150 Fuerte avocados.

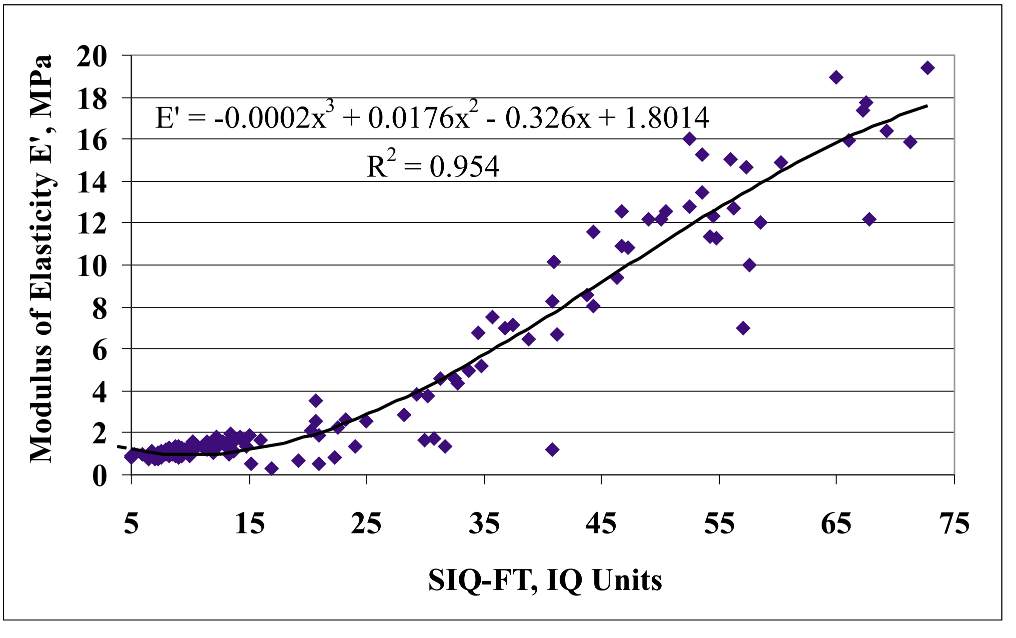


**Figure 6:** Firmness measured by SIQ-FT in IQ units vs. Modulus of Elasticity in MPa for 150 Fuerte avocados