Acoustic Technology as a Non-Destructive Quality Evaluator

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Abstract. *Adding value to the horticultural produce is becoming very important to raise the profit margin of the producer. In industrialized countries, like Japan, cost of production of fruits is exorbitantly high and loss of the produce at any stage (pre- or post-harvest) has to be well taken care of. Sonic and vibration response method is one technique for predicting the textural quality of agricultural products non-destructively. Two basic methods have been explored for use of sonic technology as a non-destructive quality evaluator, viz., resonant frequency, and sound velocity. Experiments on use of this technology to symmetrical fruits, like melons and water-melons, have been reported many years ago. By properly using the portable instrument named 'Firm Tester' successful results have been reported for even non-symmetrical fruits, e.g. pear, mango. Its use during picking would help to assure that consistent quality is being delivered to marketers, retailers, and consumers. This tester would be beneficial especially in those countries where retail price of locally produced fruits is very high due to high cost of production, and also to other countries where quality is given prime importance.*

Keywords. Acoustic, Transmission Velocity, firmness, non-destructive, value-addition.

1. Introduction

Food processing industry can add value to farm products, making agriculture industrialized and commercialized, transforming agriculture from a primary industry to a secondary and/or tertiary one, and helping farmers to gain profits not only from land but also from the output of post-harvest technology. Value can also be added to the horticultural produce as such by adopting few modern technologies. One of the major aspects of the concept of value-addition to the horticultural produce is to somehow increase the income of the farmer. This can be done by using, for example, acoustic technology, especially in those countries where retail price of locally produced fruits is very high due to high cost of production, For example, in Japan, mango used to be grown only in Okinawa Islands, but in 1999, Okinawa accounted for only 80% of the 1,406 tons grown domestically. It is also grown in Miyazaki, Wakayama, Aichi, and Kagoshima prefectures. Okinawa is located in the southeastern part of Japan and has a subtropical climate. The blooming period in Okinawa is from December to March. During this period Okinawa receives torrential rains and low-sunshine days. These conditions caused problems of flower ear damage and made the crop susceptible to anthracnose

Fig. 1. Mango plants grown in pots inside a rain-shelter shed in Okinawa, Japan.

(*Colletotrichum gleosporiodes*). In open fields, low fruit-set caused by the weather conditions was the main problem. To avoid this difficulty, in 1984, rain-shelter cultivation for mangoes (Fig. 1) was introduced by following the example of Taiwan (Akinaga and Hasbullah, 2000). The production of the mango fruit has since been steadily increasing year-by-year. However, to avoid the risk of damage to mature fruits it is necessary that mangoes be harvested before the typhoon season starts in May or June.

One of the fundamental concerns for a post-harvest researcher is to conserve the quality of the produce. In most of the fruits and vegetables, firmness is the key factor in deciding the commercial acceptance of the produce. Determination of firmness of a horticultural produce by a non-destructive method is, therefore, of prime importance. Use of such a technique during harvest would help assure that consistent quality is being delivered to marketers, retailers, and consumers. Sonic and vibration response method is one of the non-destructive techniques for predicting the textural quality of agricultural products.

Generally, optimum-eating quality requires adequate sugar and flavor development, and the center meat with a melting texture that progresses to a crisp texture towards the rind. Immature or under-ripe melons have less sugar and flavor development, and have a firmer texture than those at optimum ripeness (Sugiyama *et al.*, 1998).

Flavor and texture degrade dramatically as fruits progress from ripe to over-ripe. It is difficult to judge ripeness by outward characteristics such as size, external color, stem condition or feel. General recommendations given to produce managers are that good, ripe fruit should be firm, symmetrical and fresh looking. Determining optimum maturity, especially for fruits having high-selling price, is a critical but difficult task, even for experienced growers (Al-Haq *et al.*, 2004).

A traditional practice to determine texture of watermelon is to thump or slap the fruit and judge ripeness and defects based on the sound. Material properties of the watermelon; and other fruits like, melon, cantaloupe, *etc*.; which change with ripeness, will affect the emitted sound. A hollow, low-pitched sound generally indicates a ripe fruit. This is an adequate method only for persons with considerable experience and an objective, non-destructive technique is needed to field test fruits for ripeness (Al-Haq *et al.*, 2004). Use of such a technique during harvest would help to assure that consistent quality is being delivered to marketers, retailers, and consumers. Sonic and vibration response method is one technique for predicting the textural quality of agricultural products non-destructively.

2. Methods

Two basic methods have been explored for use of sonic technology as a non-destructive quality evaluator, *viz*., resonant frequency, and sound velocity.

2.1 Resonant Frequency

Resonant frequency has been reported by Abbott *et al*. (1968, 1992), Abbot (1994), Finney (1970, 1971, 1972). The principle applied to acquire the resonance of materials is as follows: a vibrator is used to induce a signal in the sample and the response of the material is measured by a sensing device (*e.g*., an accelerometer) attached to the surface of the product. At each frequency, a specific, inherent peak is observed. This phenomenon is recognized as resonance, and the corresponding frequency as the resonant frequency. The resonant frequency is found to be closely related to the firmness of commodities and is an inherent property of the material. Abbott *et al.* (1968) and Finney (1971, 1972) developed the methodology for some intact products and reported that f^2m (f=natural frequency, m=mass), which is designated as stiffness coefficient or index of firmness, was highly correlated with texture.

Another method used to determine the resonant frequency is based on response to impact. A microphone takes the place of the accelerometer making non-contact sensing possible, a bell pendulum takes the place of the vibrating system, and the sound can be measured instantaneously (Yamamoto *et al.*, 1980). Yamamoto and Haginuma (1984a, 1984b, 1984c) reported that sound produced by striking fruit with a wooden hammer and perceived by a microphone, when analyzed by fast Fourier-transformation, could be used to calculate the resonance representing the inherent frequency of apple, watermelon (*Citrullus lanatus* Thunb), and radish (*Raphanus sativus* L.). They compared data with that obtained by conventional compression visco-dynamic methods, and claimed a high correlation. Amrstrong *et al.* (1990) also applied a similar method to apples. The validity of an impact method was further confirmed with pumpkins (*Cucurbita pepo* L.) and radishes (Chen *et al.*, 1992), and with tomatoes (*Lycopersicum esculentum* L.) and apples (De Baerdemaeker, 1989). All data correlated with those obtained by a penetrometer. Collectively, all these methods primarily employ resonant frequency in the analysis. Resonant frequencies are affected by the size and shape of the sample. Moreover, the mechanism of producing multiple resonant frequencies in some produce was not clarified by experimental evidence (Sugiyama *et al.*, 1998).

2.2 Sound Velocity

Measurement of sound velocity with ultrasonic waves has also been applied to various agricultural products. Garrett and Furry (1972) gave an account of use of sound velocity method. Mizrach *et al.* (1989) suggested that the velocity of ultrasonic sound could be used for ripeness classification in some fruits and vegetables. Self *et al.* (1994) showed that the ultrasonic velocity decreased in avocado flesh (*Persea americana* Mill.) as a function of ripening stage. Zebrowski (1992) also applied the ultrasonic method to measure the stiffness of stem and leaf sheaths of triticale (xTritiosecale). However, in most of these ultrasonic measurements, the attenuation coefficient was extremely high because of the amorphous nature of fruit and vegetable tissues (Mizrach *et al.*, 1989; Sarker and Wolfe, 1983). Therefore, it is difficult to reliably measure the velocity of ultrasonic sound through these commodities. Generally, the attenuation coefficient decreases as the frequencies imposed on the material are lowered. Thus, relatively low frequencies (audible range) were applied for evaluation of texture of fruit. As a consequence, Muramatsu *et al.* (1996) demonstrated that changes in phase of transmitted sound could be readily determined and used as a firmness index. Sugiyama *et al.* (1994) stated that utilization of the transmission velocity as a measure of firmness has two major advantages over resonance frequency technique, *viz*., the transmission velocity (TV) method compensates for variations in the size of the samples, because the circumference of the sample is included in the calculation, and it is easy to detect the maximum peak in the impact waveform for calculation of TV (Sugiyama *et al.*, 1998). Magnitude of TV depicts more firm fruit.

3. The Instrument 'Firm Tester"

The instrument named 'Firm Tester' (Fig. 2) is being commercially manufactured by Toyoseiki Co. Ltd., Tokyo. Al-Haq and Sugiyama (2003, 2004b,c) and Al-Haq *et al* (2004c) in their studies used its model SA-1. It employs acoustic technology and gives digital readings of transmission velocity (m/s) as a firmness index. The instrument (Fig. 2) consists of an impulse generator, an amplifier, a PC card (Analog/Digital (A/D) converter), and a personal computer (PC). Pulling the trigger of the firmness tester starts the measurement and the result appears on the PC screen in less than a second (Fig. 2b). The impact rod and the two microphones are in line with each other. The distance between two microphones was set to 16 mm apart from each other. The vibration produced by the impact is transmitted in all directions on the surface of the sample. Two microphones detect the traveling vibrations as sound signals. Due to 16 mm separation between the microphones, there is a slight time difference in their detection of sound signals. The sound signals are amplified and transmitted to the computer through an A/D converter. The sampling frequency was selected to 200 kHz per channel. The data can be taken either by holding the fruit in hand (Fig. 1a) or placing it on a stay (Fig. 1c). The data was taken at different places on a fruit.

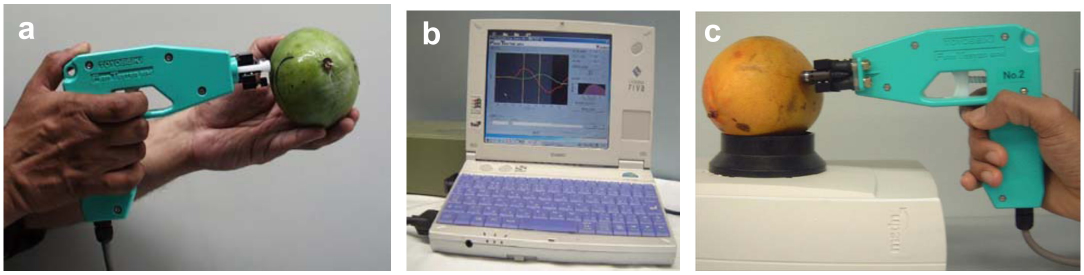

Fig. 2. Determination of transmission velocity of 'Keitt' mangoes by using 'Firm Tester' attached with a PC

(a) mango in hand, (b) PC used to record data, (c) mango placed on a stay

[Al-Haq & Sugiyama., 2004c]

4. Results and Discussion

Sugiyama *et al.* (1994, 1998) successfully used this instrument for determination of fruit firmness non-destructively for muskmelon. A modified version was then used for pear (Sugiyama, 2001). While, Al-Haq and Sugiyama (2004b,c), Al-Haq *et al.* (2004) and Sugiyama *et al.* (2005) used it for different cultivars of mango, and cantaloupe (muskmelon).

Al-Haq *et al*. (2004) reported that they could detect the difference in the firmness of the muskmelon fruits grown by applying different amount of manure, *i.e.*, 20 and 50 tons/hectare. They marked four locations on each melon (cantaloupe) and TV was measured, mean value was calculated and used as non-destructive firmness index. They found that the relationship between TV and storage days was nearly linear (please see Fig. 2 of Al-Haq *et al.*, 2004). Cantaloupe grown in 20 t/ha manure had higher velocities than those grown in 50 t/ha manure. Hence, the 50 t/ha manure produced softer cantaloupe. Cantaloupe harvested 59 days after pollination had a velocity of 54.5±2.5 m/s, 63 days after pollination had TV of 55.7±5.7, whereas 67 and 71 days after pollination had TV of 49.60±4.8 and 46.8±0.4 m/s, respectively (Al-Haq *et al.*, 2004). Hence, the slowest velocity recorded by the instrument reflected softer fruits and the data showed that the most firm fruits were those harvested 63 days after pollination. The regression coefficient (slope) of regression equation showed reduction in TV per day (Table 2 of Al-Haq *et al.*, 2004). All this data was validated by sensory evaluation and total soluble solid (°Brix) contents. The statistical analysis showed correlation of r=0.907 between scores of sensory evaluation and TV (Al-Haq *et al.*, 2004).

Al-Haq and Sugiyama (2003) used 'Irwin' mangoes, stored at 5°, 10°, 15°C and in ambient conditions (20° to 25°C) to determine firmness by using Firm Tester. They reported that the instrument provided with true firmness index of Irwin mangoes non-destructively.

Al-Haq and Sugiyama (2004c) carried out another study, by using this instrument, on 'Keitt' mangoes with the objectives to (1) judge the most appropriate place on a mango fruit that could reflect the firmness, (2) find the range of TV of the ripened 'Keitt' mangoes, and (3) TV at the best eating time of 'Keitt' mangoes. Mango is a non-symmetrical fruit. Therefore, the instrument 'Firm Tester' gave different TV when used at different locations on a mango fruit. The orientation of a fruit also made the difference in the determination of TV. If it is held at upright position (vertically) then sometimes the reading cannot be taken, as the two microphones will not be at the equal distance from the surface of the fruit because mango is a non-symmetrical fruit. The proper way to take the observation was to hold the mango fruit either by hand (Fig. 2a) or place it on a stay (Fig. 2c), but care should be taken that data is taken by placing it horizontally as shown in Fig. 2. The data taken by placing a fruit on a stay was more reliable as the fruit was more stable in that position than holding it in a hand.

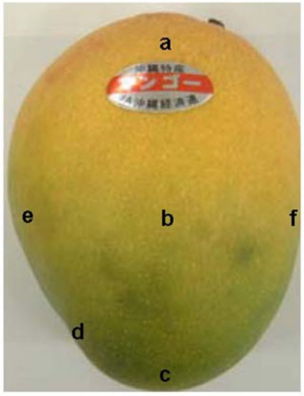

Fig. 3. A 'Keitt' mango fruit,
(a) stem end, (b) thick flat pulpy
(b) side, (c) blossom end, (d) apex,
(e) suture side, and (f) thin side
[Al-Haq and Sugiyama, 2004c]

Mango starts ripening from top to bottom and from centre to the sides. The flat pulpy side has the greatest amount of pulp (Fig. 3b). This side is considered prime and relished by the consumers, so they judge quality of a mango fruit by eating this portion. Therefore, Al-Haq *et al*. (2004c) were of the viewpoint that the most appropriate place that reflects the firmness of mango is the thick pulpy side. They also stated that a non-ripened fruit on a tree in Okinawa Island (the major mango growing area in Japan) had TV of 70 to 80 m/s. Whereas, the mean TV of the harvested 'Keitt' mangoes when they reached Tsukuba city was 58 m/s. Properly ripened mangoes had TV of 20 to 32 and the best eating time was when they had TV of 24 to 28 m/sec. The minimum TV of a healthy 'Keitt' mango was 16 m/sec, and the lowest value of a decayed mango that Firm Tester detected was 10 m/s.

Al-Haq and Sugiyama (2004c) also observed that readings for TV on one side of some fruit were quite lower than the other sides. When such fruit were cut the internal breakdown of the pulp was observed (Fig. 4). Hence, the Firm Tester is a useful tool to judge the inside texture of the fruit non-destructively, because morphologically those fruit were equally good to the good-ones, but anatomically had inferior quality due to the internal breakdown.

The manufacturer of the Firm Tester is now interested to boost up the production of the instrument and reduce its selling price. The R&D section is nowadays busy in developing a new model that would not need a PC and a small display-screen will be fixed behind the trigger of the pistol-shaped instrument. It is hoped that it will reduce the cost of the instrument enormously.

So far, studies have published on the use of Firm Tester on apple, muskmelon (cantaloupe), watermelon, pear and mango fruits. Further studies may be carried out on pineapple, durian, mangostene and/or other non-symmetrical fruits.

Fig. 4. A type of internal breakdown in mango [Al-Haq and Sugiyama, 2004c]

5. Conclusions

The Firm Tester provides with true firmness index of symmetrical (apple, cantaloupe, watermelon) as well as non-symmetrical (pear, mangoes) fruits non-destructively. It can be used by farmer, shipper, whole-seller and/or retail shopper to judge the on-going life stage of a horticultural produce. This tester would not only be beneficial to countries, like Japan, where concept of adding-values to the horticultural produce has already been commercialized but also in those countries where efforts are being made to disseminate the concept of added-value.

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