Acoustic Vibration Technique: Novel Non-Destructive Technology – A Critical Review

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Abstract- *Storage conditions of food products affect its subsequent softening process and shelf life. Measurements of quality parameters have traditionally been carried out using a texture analyzer or penetrometer in reference texture tests. In this study, a non-destructive method using Acoustic Vibration Technology (AVT) was used to estimate quality parameters of the food products. This technique was employed to detect responses to imposed vibration of intact food material using a shaker. A fast Fourier transform algorithm was used to process response signals and the desired results were extracted. This study shows the capability of the AVT and the vibration response data for predicting quality and the significant advantage for commercial scale equipments.*

Keywords- Acoustic vibration, quality and non-destructive technique.

I. INTRODUCTION

Quality is related to both internal variables (firmness, sugar content, acid content and internal defects) and external variables (shape, size, external defects and damage) of the product. Increasing consumer demand for high-quality product has led to the development of novel technologies for quality assessment like optical, acoustic and mechanical sensors. Presently these quality variables are assessed by destructive method in which the entire product sample is disturbed. Due adoption of destructive method of quality assessment, product may lose some of its attributes before analyzing its attributes. Such a process involves lot of chemical analysis, calculations and mainly time consuming. But processors are needed to measure these quality variables in a non-destructive manner to retain its inherent characteristics. This problem initiates the researchers and manufacturers to develop non destructive techniques.

Presently consumers are focusing on the quality of agricultural products when deciding on purchases; therefore, evaluation of the quality of agricultural products is important not only to farmers but to food processors and distributors also. There are various factors in quality evaluation, such as appearance, taste, and fragrance, among which, texture is an important attribute. Desired textures include hardness, crispness, juiciness, and mealiness (Mitsuru and Naoki, 2010).

According to British Standards Institution, the texture of an edible material is defined as the attribute of a substance resulting from a combination of physical properties perceived by the senses of touch (including kin aesthesis and mouth feel), sight and hearing (Anonymous, 1975).

Fruit firmness is one of the most important quality variable; it is an indirect measurement of ripeness and its accurate assessment allows appropriate storage periods and optimum transport conditions to be established (García et al., 2005).

Firmness, together with the determination of sugar and acid content, represent important parameters used in the objective evaluation of fruit and vegetable quality. Of these three, firmness probably remains the most subjective, because the relatively simple output of the force of a probe on fruit surfaces is used to interpret complex rheological behavior (Muramatsu et al., 1997).

In most of quality evaluations, a representative samples were selected and evaluated for maturity and texture control and then the product is discarded. The limited sampling does not effectively account for the total variation in maturity at harvest and makes it difficult to monitor subsequent changes that may develop during storage (Falk et al., 1958).

Moreover, in the specific evaluation of kiwifruit there is no external evidence reflected by colour that would facilitate the assessment of uniformity within bulk shipments (Muramatsu et al., 1997). Hence, an additional comprehensive non-destructive method for product evaluation would have distinct advantages for quality control. Several methods for non-destructive firmness measurement have been reported by Falk et al., 1958; Finney 1970; Yamamoto and Haginuma, 1984a,b,c and Abbott 1994 for different food products.
Due to the technological advances over the past few decades have led to the growth of non-destructive devices like image processing, visible and infrared light inspection, acoustic vibration technique, NMR technique and mechanical simulation capable of measuring product internal variables. Initially, these were developed to utilize in the laboratory, but

have been fitted for on-line use. This article describes detailed methodology, components, working principle and applications of acoustic vibration technique to measure or assess the quality of the food products.

II. METHODOLOGY

Non-destructive quality evaluation

Various methods evaluate the texture of agricultural products based on deformation force (e.g., the puncture test and compression test). The quality evaluation of agricultural products is supposed to be an inspection of samples when we use these methods because they are destructive. For better quality control of agricultural products, one hundred percent inspection is preferable; therefore, nondestructive evaluation methods are highly in demand. Hence, the several nondestructive methods for the quality evaluation of agricultural products that are widely used or under development.

2.1 Deformation method

Deformation methods can be nondestructive as long as the deformation is small enough not to damage an agricultural product. The basic principle governing the measurement of force – deformation lies in Hertz's theory; the compressive stress between two bodies in contact is proportional to their elastic modulus and inversely proportional to their radius. Here, one of the bodies is the fruit and the other a metallic plunger (either a small sphere or flat-ended probe). By applying a small deformation force to the fruit in such that it causes no damage, the non-destructive force-deformation curve can be recorded using an analogue or a piezoelectric sensor positioned at the back of the compression plunger. The curve is produced by applying a small load for a fixed period of time (Macnish et al., 1997) or by calculating the force necessary to reach a pre-set deformation (Fekete and Felföldi, 2000).

2.2 Acoustic vibration technique:

When an acoustic wave reaches a food product, the reflected or transmitted acoustic wave depends on the characteristics of the product. Acoustic technology is often used to estimate product firmness along with other quality parameters (Maristella and Marina, 2012). Acoustic firmness index is based on the relationship between modulus of elasticity and the resonant frequencies of vibration of the fruit.

The acoustic vibration technique further classified according to sensors for vibration detection and excitation methods (Figure 1). There are two kinds of sensors: contact and noncontact sensors. Contact sensors are directly attached to the surface of the sample under examination. Such sensors that are commonly used include acceleration pickups and piezoelectric sensors. Noncontact sensors include microphones and optical sensors such as laser Doppler vibrometers (LDVs) and laser interferometers. The advantages of noncontact sensors are that they are totally nondestructive and exert no physical or mechanical influence; therefore, they do not damage the surface of a sample.

The acoustic response technique for measuring fruit firmness has been studied with two different approaches: involving values within the audible spectrum (sonic) or using ultrasound (Maristella and Marina, 2012). According to Subedi and Walsh (2009), the sound velocity of the vibration produced by the fruit hit by a plastic plunger, detected by two unidirectional microphones, was demonstrated to non-destructively assess the ripening stage of banana, mango and peach fruits, although it does not measure the same property as the penetrometer whereas the vibrational response of pear (Terasaki et al., 2006; Taniwaki et al., 2009a), melon [Taniwaki et al., 2009b; Taniwaki et al.,2010c] and persimmon fruits was sensed by means of a laser Doppler vibrometer and an acceleration pickup and the Elasticity Index, determined by using both signals, highly correlated with the results of a sensory test. The authors concluded that this technique can be useful for predicting the optimum ripeness for edibility of these fruits but that the difference in texture attributes is explainable only in part by the frequency bands.

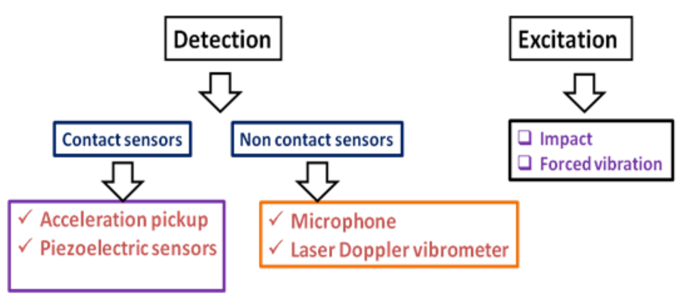

Figure 1. Classification of Acoustic vibration technique

Different types of vibrations can be used, the most common being acoustic and mechanical (which in some cases are very similar). Using a microphone or a piezoelectric sensor, acoustic methods measure the signal (audible range: about 0 – 20,000 Hz) issued by the fruit after making it vibrate by means of a small impact. The acoustic signal captured is Fourier transformed and the main frequency calculated. The range varies from 5 MPa for green fruit to 0.5 MPa for overripe fruit (Studman, 1999).

Components of the Acoustic vibration equipment

Basically the experimental setup consists of a platform over which the sample was placed. Sensitive sensors (contact type or non-contact type) like Microphone, piezoelectric sensors, Laser Doppler vibrometer or any other sensors were placed either attached to the product or in other indirect form to sense the vibration or frequency after applying the little force to the product. Force required to generate the vibration can be applied with the help of pendulum arrangement consisting of either ball or small probe. Then the quality parameters of the product can be determined by analyzing the frequency or vibration with the help of Fast Fourier Transformation (FFT) analyzer. Typical experimental setup of Acoustic vibration equipment consisting all its components was shown in the Figure 2. Then the frequency 'f' of the model is given by;

$$f = \frac{1}{2\pi}\sqrt{\frac{4k}{m}} \quad \text{and} \quad k = \pi^2 f^2 m$$

Where 'k' is the spring constant of the system and 'm' is the mass of the sample.

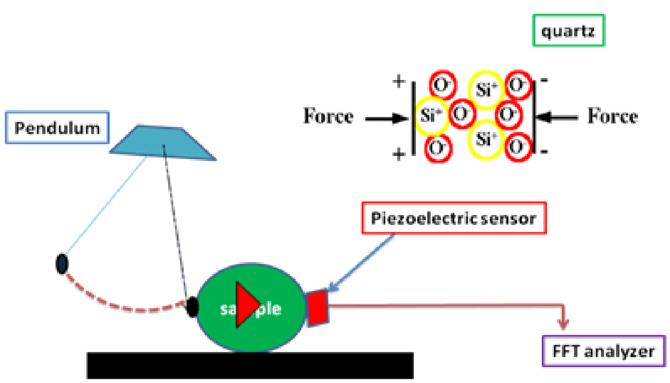

Figure 2. Experimental setup for excitation by impact and detection by piezoelectric sensor based acoustic vibration technique

Applications of the acoustic vibration technique in quality

In order to assess the quality and maturity indices of fruits and vegetables, various parameters were considered which are tabulated in Table 1.

Sl. No	Index	Method of Determination	Examples
1.	Elapsed days from full bloom to harvest	Computation	Apples, pears
2.	Mean heat units during development	Computation from weather data	Apple
3.	Development of abscission layer	Visual or force of separation	Some melons, apples, feijoas
4.	Surface morphology and structure	Visual	Cuticle formation on grapes, tomatoes; netting of some melons; gloss of some fruits (development of wax)
5.	Size	Various measuring device, weight	All fruits
6.	Specific gravity	Density gradient solution; flotation techniques; volume/weight	Cherries, watermelons
7.	Shape	Dimensions; ratio charts	Angularity of banana finger; full cheeks of mangoes
8.	Firmness	Firmness tester, deformation	Apples, pears, stone fruits
9.	External colour	Light reflectance, visual colour charts	All fruits
10.	Internal colour and structure	Light transmittance, delayed light emission, visual examination	Flesh colour of some fruits
Compositional Factors			
11.	Total solids	Dry weight	Avocados, kiwifruit
12.	Starch content	KI test, other chemical tests	Apples, pears
13.	Sugar content	Hand refractometer, chemical tests	Apples, pears, stone fruits, grapes
14.	Acid content, sugar/acid ratio	Titration, chemical tests	Pomegranates, citrus, papaya, kiwifruit
15.	Juice content	Extraction	Citrus fruits
16.	Oil content	Extraction, chemical tests	Avocados
17.	Astringency (tannin content)	Ferric chloride test	Persimmons, dates
18.	Internal ethylene concentration	Gas chromatography	Apples, pears

Destructive methods can be applied only on a limited batch, and is therefore not always representative of the whole sample. The tendency of using as few samples as possible often results in increased lot to lot variability in the parameter measured. At harvest there is always variability among picked fruits even when, on the average, they conform to the harvest parameters.

In contrast, non-destructive methods can be applied to a high number or even to all fruits and non-destructive analyses can be repeated on the same samples, monitoring their physiological changes (Nicolaï et al., 2007)

A number of reviews on non-invasive technologies for fruit and quality sensing have been published concerning visible (VIS) and near infrared (NIR) spectroscopy, multi- and hyperspectral imaging, time- and space-resolved reflectance spectroscopy, computer vision, nuclear magnetic resonance (NMR) and magnetic resonant imaging (MRI), acoustic methods and wireless sensing (Ruiz-Altisent et al., 2010). This review highlights spectral maturity indices as well as nondestructive mechanical techniques developed in the last few years for the assessment of fruit ripening. Table 2. Indicates the methods used and parameters considered for non-destructive evaluation of different fruits and vegetables.

Table 2. Methods and parameters used for non-destructive evaluation of different products

Crop	**Method**	**Parameters used**	**Reference**
Apple	Acoustic, VIS-NIR spectroscopy	Acoustic resonance frequency, fruit absorbance	Zude *et al.*, 2006
Apple	Acoustic (ultrasound)	Wave velocity	Kim *et al.*, 2009
Apple	Acoustic, low mass impact, impacttest, compression test, puncture test	Maximum deformation, maximum force, acoustic frequency	Molina-Delgado *et al.*, 2009
Banana, mango, peach	Acoustic	Sound velocity	Subedi *et al.*, 2009
Kiwifruit	Dynamic impact	Peak of force, pulse duration, impulse	Ragni *et al.*, 2010
Melon, persimmon, pear	Acoustic	Resonant frequency	Terasaki *et al.*, 2006 Taniwaki *et al.* 2009a
Orange	Acoustic (ultrasound)	Wave velocity and amplitude	Camarena *et al.*, 2006, Jiménez et *et al.*, 2012
Peach	Impact and acoustic	Maximum acceleration, resonant frequency Spectrum amplitude, band magnitude	Diezma-Iglesias *et al.*, 2006
Peach	Impact	Resonance frequency	Wang et *et al.*, 2006
Peach, nectarin, plum	Hammer impact	SFI score from SIQ firmness tester	Valero *et al.*,2007
Peach	VIS spectroscopy, impact, deformation test	Force and time impact, maximum force, reflectance R680 and R450	Ruiz-Altisent *et al.*, 2006
Peach	Impact and acoustic	Resonance frequency of the first elliptical mode	Ruiz-Altisent *et al.*, 2010
Peach	VIS spectroscopy, impact	Reflectance, maximum impact acceleration, impact hardness, time for maximum acceleration, maximum deformation	Herrero-Langreo *et al.*, 2012
Pear	Ball impact	Resonant frequency	Hernandez-Gomez *et al.*, 2005
Tomato	Acoustic (ultrasound)	Wave attenuation	Mizrach, 2007
Tomato, apple	Impact and acoustic	“SIQ-FT” index (calculated by force peak amplitude and impact response).Resonant frequency	De Ketelaere *et al.*, 2006

III. CONCLUSION

For the nondestructive evaluation of agricultural products, one approach is to develop devices that are more practical and cost-effective in evaluating the optimum quality attributes. Such devices are currently under development. Another approach is to gain a theoretically in-depth understanding of the acoustic vibrations of agricultural products. Although there have been studies on the vibrational modes of different shapes (Cherng, 2000; Cherng and Ouyang, 2003; Jancsok et al., 2001) for instance, the vibrational characteristics of agricultural products, such as watermelons, that consist of two-layered spherical shells have not been fully analyzed. Understanding such dynamics would help in developing a methodology for obtaining inner quality information on agricultural products.

The AVT used for quality estimation are simple, cheap and acceptable results were obtained, but non-destructive techniques do not necessarily measure the same quality attribute as their destructive counterparts. Moreover, the authors often observed poor relationships between acoustic firmness and M-T test, and non-destructive impact measurements were found to be highly sensitive to change in turgidity but less able to follow changes in ripening.

Future studies should focus on the simultaneous use of different ND techniques. In such a way the resulting information is more complete and accurate than that obtained when an individual technique has been used.

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