Acoustic Resonance Technique, A Potential Non Destructive Method for Quality Evaluation of Agricultural Product

R. Amala Infanta Shirly, R. Jency Dhivya,
G. Kamala Devi, G. Mary Amirtha Sagayee
Parisutham Institute of Technology and Science, Thanjavur

Dr. V. R. Sinija
Indian Institute of Crop Processing Technology, Ministry of Food Processing Industries,Government of India, Thanjavur

Abstract- Many destructive methods are used to judge the quality of fruits and vegetables. Many non-destructive methods of quality evaluation Image processing, Near infrared spectroscopy (NIR), Electrical impedance spectroscopy (EIS), X-ray scanning and Acoustic Resonance Technique. A non-destructive quality evaluation of fruits and vegetables can be done by using acoustic resonance technique. In this study the fruits are impacted and resulting sound waves are captured by a microphone to obtain the time domain signals which are then transformed into frequency domain using smart office digital signal analyzer (SO analyzer) which works on Fast Fourier Transformation concept. The frequency which is obtained the most is considered and is known as dominant frequency. The dominant frequency is the function of elasticity and mass of the sample. The dominant frequency can be compared with the physical characteristics of the fruit or vegetable after destruction. The acoustic studies of different products like watermelon and other melons, potato tuber, walnut and tomato have been done already.

Keywords-* *Non-destructive quality evaluation, acoustic resonance technique, digital signal analyzer, dominant frequency range, most dominant frequency, physical characteristics

1.INTRODUCTION

Acoustics deals with sound fields, i.e. with the description and explanation of the phenomena of sound generation, sound emission, sound propagation and sound absorption. Acoustic waves require a physical medium through which they can propagate. Nearly all objects will vibrate when they are hit or excited or somehow disturbed. A body contains thousands of acoustic modes within the frequency domain. The frequency or frequencies at which the objects tend to vibrate after excitation is called natural frequency/ frequencies or resonances. The resonances depend uniquely on the object's material, geometry and condition. Each of these modes represents a standing wave at a natural frequency. Whereas a flute for example tends to vibrate at a single frequency, other objects create multiple sets of frequencies that have no (simple) mathematical relationship between them. So an acoustic wave can be understood as a longitudinal pressure wave that alternately pushes and pulls the substance through which it propagates.

Acoustic resonance is the tendency of an acoustic system to amplify a frequency that matches one of its own natural frequencies of vibration than it does at other frequency. An acoustically resonant object usually has more than one resonance frequency, especially at harmonics of the strongest resonance. The most familiar example of acoustic resonators are musical instruments. Some generates the sound directly such as the wooden bars in a xylophone, the head of a drum, the string in the stringed instruments, and the pipes in the organ. Acoustic resonance is also important for hearing.

Acoustic resonance analysis for non-destructive testing of materials in mass-production, as offered by RTE Akustik + Prüftechnik GmbH is a proven technology. having been successfully implemented in various industries. What is new is the industrial application of these methods to everyday manufacturing of various products in many industries. Modern, high-power computer systems can "audit" human hearing. Reliable integration into a production cycle of a few seconds, under mass-production conditions, is possible without any difficulties.

Acoustic resonance analysis is a new, non-destructive testing process that allows rapid and cost-effective 100% testing of a wide spectrum of test objects. Texture is one of the most important quality factors of agricultural products. One non-destructive technique for predicting the textural quality of agricultural products is the response to sound and vibration. Most acoustic food evaluation systems have been developed to detect firmness in agricultural products. Firmness is the indication of maturity and ripening stages. By using acoustic resonance technique, non-destructive method for quality evaluation firmness of agriculture products can be detected.

II.LITERATURE REVIEW

The possibility of applying the acoustic impulse response method to fruits with non-uniform internal structures was considered experimentally by studies on tomatoes . In this case , correlations were established between the coefficient of elasticity calculated from acoustic measurements , colour measurements (lightness and hue) , the force required to compress the whole fruit by

3% of its equatorial diameter , and the modulus of elasticity calculated from the whole fruit load-deformation curve .

Acoustic response measurements gave a reliable indication of the change in mechanical properties of fruit before , during and after harvest . In particular there were indications that the acoustic response may give additional information on fruit water status which is not detectable by conventional firmness measurements. Given the non-destructive nature of acoustic response measurements, the method appears to have considerable promise as a technique for the evaluation of the post-harvest condition of tomatoes .

2. PROPOSAL WORK

A.Materials

The acoustic method was also used for characterizing tomatoes , a fruit which has an internal structure with a range of different zones with different firmness levels . A sample of 90 fruit with colours ranging from green to red was subjected to acoustic tests and compression measurements as before , and also to colour measurements , in which the L , a , and b chromatic coordinates were determined with a Minolta CR-300 Chromameter (L , a , and b refer to the lightness , hue (or colour) , and chroma (or purity of the colour) respectively).

B. *Tomatoes Measurements*

The firmness of the tomatoes was monitored with the acoustic impulse-response method. The tomato was placed with the stalk sideways on a support covered with foam rubber. In this support at a few mm from the fruit surface, an upward directed MC101 microphone was mounted. The tomato was excited by gently impacting it on the equator at the opposite side of the microphone with a solid plastic rod. After filtering the signal with a force and exponential window, a Fast Fourier Transformation was performed by a Hewlett Packard signal analyzer HP35665A. In the resulting frequency spectrum, the first resonance frequency was selected (De Baerdemaeker, 1988; Chen et al., 1992). Arbitrarily, only frequencies of which the peak amplitude was larger than 50% of the overall peak amplitude were considered in this selection. Fig. 1 shows a typical frequency spectrum for a tomato and the selected peak. The measurement was performed at three locations on the fruit equator and the average was used for further processing. The mass of the tomato was measured with a precision balance. The stiffness *S* was calculated from Eq. (1) and expressed in stiffness units with dimension $10^6 Hz^2\ g^{2/3}$

C. Universal Testing Machine (Uts)

In experiment 3 the firmness of the tomatoes was also tested, non-destructively, every two or three days by parallel plate compression in a universal testing machine (Schotanus, 1994). The fruits, positioned with their stem horizontal, were compressed between two parallel plates at a speed of 0.67 mm:s until a force of 3 N was reached. The displacement (mm) was recorded. When al l50 fruits in the group had a compression of more than 1.1 mm, the test period was ended. This was usually after more than 14 days of storage.

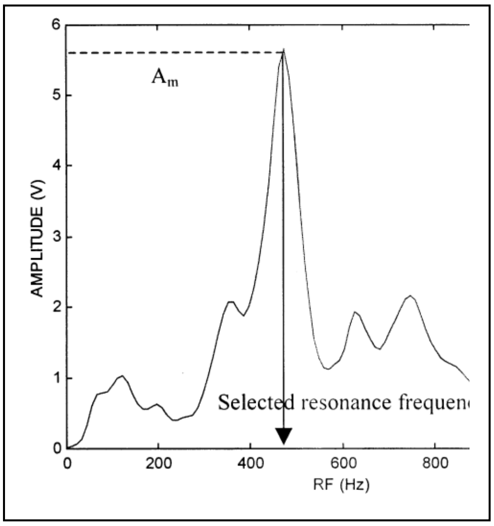

Fig.1 Amplitude Vs Frequency

C. Acoustic Impulse-Response Method Vs. Expert Judgement

To establish the relationship between objective and subjective firmness measurements, 100 fresh tomatoes of different varieties and of different firmness were obtained from a grower. They were picked in April on four different harvest dates, and included tomatoes of varying maturity. The tomato firmness was measured by four market experts and with the acoustic impulse-response device. The tomatoes were presented to the experts in groups of five, which allowed them to compare tomatoes within a group. They attributed a firmness score to the tomatoes of 1 (very soft) to 10 (very firm). The repeatability of both methods was tested by repeating the measurements three times on a group of 20 tomatoes.

D. Smallest Detectable Firmness Difference And Lowest Acceptable Firmness

Five market experts were checked for accuracy and consistency. The three experts that gave the most consistent and accurate scores were retained for the experiment. During 3 consecutive weeks, 200 fully red tomatoes were obtained from a Belgian experimental station. They were stored for 10 days at 12°C and 95% RH, and then for 3 days at room temperature, to enhance ripening. With the acoustic impulse-response technique, ten groups of three tomatoes were created, of which two tomatoes showed the same stiffness *S* (90.2*$10^6 Hz^2\ g^{2/3}$) and the third a stiffness difference of 2.5*$10^6 Hz^2\ g^{2/3}$. This was repeated for stiffness differences of 1.5 and 0.8*$10^6 Hz^2\ g^{2/3}$. In each series there were groups with firm as well as groups with soft tomatoes. The experts were asked to select in each group the tomato with different firmness. This experiment allowed determination of the smallest detectable firmness differences. To determine the lowest acceptable firmness, the experts examined 400 tomatoes, after measurement with the acoustic impulse-response method. The experts were asked to divide the tomatoes into three groups according to the firmness: accepted, rejected or questionable. Each tomato was classified by all three experts. For the analysis of the results, the tomatoes were arranged in order of increasing stiffness factor and grouped per 0.2*$10^6 Hz^2\ g^{2/3}$ with at least five tomatoes (15 acceptance scores) in each group. The chance of being accepted or rejected was calculated as a function of the average stiffness of the group.

E. Experiment 3: changes in firmness of tomatoes during storage

The aim of this experiment was to use the acoustic impulse-response technique to study changes in firmness of tomatoes during storage. Mathematical description of change in firmness allows the establishing of a prediction model. The hypothesis is that for a given storage temperature, the change of the stiffness factor *S* as a function of time, can be expressed as a first order degradation model. This assumption was also made by Thai et al. (1990).

$$\frac{ds}{dt} = - \alpha\ s \qquad (1)$$

$$S = S_0\ e^{-(\alpha,t)} \qquad (2)$$

where ***S*** is the stiffness factor at time *t* ($10^6 Hz^2\ g^{2/3}$);
S_0 is stiffness at the initial time 0 ($10^6 Hz^2\ g^{2/3}$);
a is the deterioration constant, which is temperature dependent (1:day);
t is time (days).

This model assumes that all individual fruits follow the same hypothetical path of maturity change although they may not be at the same stage at any one time. Therefore we should be able to find for each tomato a time shift t, which is a function of the individual stiffness at the initial measurement. This time shift t essentially shifts the function *S* along the time axis so that it coincides with the hypothetical path. In the current work the influence of different variables on the deterioration rate was examined. Variables included tomato segment, producer, season, colour at picking and storage conditions.

In Belgian auctions, tomatoes of high quality are divided into different ‘segments’ according to their specific characteristics, growing conditions, subjective judgements by auction experts, and a number of measured quality parameters. Three important segments for tomatoes in Belgium are Baron, Prince and Excellent. Each segment can include different varieties. In this experiment the varieties Blitz for Baron, Tradiro for Prince and Recento (winter) or DRW 3450 (spring, summer, autumn) for Excellent were used.

In auctions, the colour at the blossom end of the tomato at harvest is expressed as a value from one (green) to twelve (very red). During the period from the beginning of October until the beginning of May, fruits are normally harvested when they reach a colour of eight. In summer they are picked at a colour of 5. The experiment started at the end of November (winter) and for the three segments, fruit of colour 9, originating from two different growers, was obtained from the auction. In spring tomatoes of colour 6 (orange) and of colour 9 (red) at harvest were examined, while in summer fruit with colour 8 was obtained.

The tomatoes were stored at 95% RH, and in spring, summer and autumn 12° and 20°C storage temperatures were compared. In spring, red fruit were also stored at 2°C (Prince and Excellent), and in autumn at 2 and 8°C (Excellent).

For each combination of variables 50 fruit were tested. During a period of at least 14 days, every 2 or 3 days the stiffness of the tomatoes was measured with the acoustic impulse-response technique.

The test period was ended when all 50 fruits in the group showed a parallel plate compression in a universal testing machine of more than 1.1 mm. Both measurement techniques are non-destructive and we checked that measurements did not cause any soft spots in the fruit.

Because high temperatures enhance ripening, it can be expected that for the same season and the same segment, the firmness will decrease less at lower temperatures. However, care must be taken to avoid chilling injury at temperatures below 6°C, inducing a soft and watery structure. The damage caused is worse for green than for red picked tomatoes (Barret et al., 1998). The influence o temperature is often expressed in form of an Arrhenius equation:

$$\alpha = \alpha^{\infty} \exp\left(-\frac{E_a}{R_g T}\right) \qquad (3)$$

where, a_is the deterioration constant at infinite temperature (1:day);
*E*a is activation energy (kJ: kmol);
*R*g is the universal gas constant (8.314kJ: kmol K);
T is absolute temperature (K)
This equation is often used in another form:

$$\alpha = \alpha^{ref} \exp\left(-\frac{E_a}{R_g T}\left(\frac{1}{T} - \frac{1}{T_{ref}}\right)\right) \qquad (4)$$

where α_{ref} is the deterioration constant at T_{ref} (1:day);
T_{ref} is the reference temperature (K).
For red picked tomatoes in autumn and with a reference temperature of 15°C the values of α^{ref} and *E*a were calculated.

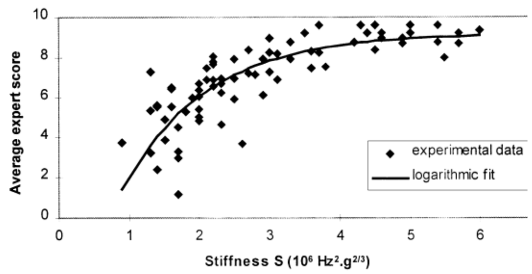

Fig. 2. Relation between stiffness factor *S* measured with the acoustic impulse-response technique and the average expert scores.

III. RESULTS AND DISCUSSION:

Experiment 1: acoustic impulse-response method vs. expert judgement

When the expert scores for the same tomatoes were compared, a discrepancy between the different experts was found. Some experts never gave a firmness score below 5, even for very soft tomatoes that would receive a 2 or less from other experts. This implies that comparison of tomato scores between auction house experts requires rescaling. Fig. 2 shows a logarithmic relationship between stiffness *S* and average score, after rescaling, given by the three most consistent experts. To express the measured stiffness *S* as an expert score, the following relationship can be used:

for $0 \leq S \leq 0.7$ expert score = 0

for $S>0.7$: expert score = 9.2(1- $e^{(=0.84(S-0.7))}$)

The overall $R2$ value amounts to 0.79 and the SEM of the model is 1.45. Estimates of the asymptotic standard error for the model parameters 9.2 and _0.84 are 0.34 and 0.084, respectively.The shape of the curve indicates that experts hardly notice firmness differences in firm tomatoes.

When the three repetitions of each expert measurement are considered as randomly chosen samples out of a normal distribution, the variance within a measurement or the variance of the error σ_e^2 can be estimated by the pooled variance: S_{es}^2 = 0.429 * (10^6 Hz^2 $g^{2/3}$)^2 for the stiffness factor *S* and S_{eE}^2 = 0.724 for the rescaled expert scores. To obtain an estimate, *s*2 b, of the variance between measurements s2 b, we can assume that the difference between a measurement and the mean of the distribution of all measurements is no more than two or three times sb. Knowing the range *G* (6.3*$10^6 Hz^2$ $g^{2/3}$) for the stiffness factor *S* and 10 for the expert scores), this assumption provides us with a high (*s*bh_*G*:4) and a low (*s*bl_*G*:6) estimate of σ_b. A high and a low estimate of the repeatability *t* and the accuracy *R* of the measurements may thus be calculated (Torreele, 1991; De Belie, 1995):

t = s_b^2 / ($s_b^2 + s_c^2$)

R = $[n.t/(1+(n-1).t)]^{1/2}$

where *n*, the number of repetitions per measurement, is 3. The results are presented in Table 1. Accuracy and repeatability of the stiffness measurements *S* and of the expert scores are about the same. However, the advantage of the stiffness factor *S* is that it is obtained objectively and no rescaling problems occur.

Experiment 2: smallest detectable firmness difference and lowest acceptable firmness

As expected from experiment 1, this test proved that it is easier for experts to distinguish firmness differences in soft than in firm tomatoes: more correct selections were made in groups of tomatoes with a lower average firmness. In relatively soft fruit (SB5*$10^6 Hz^2$ $g^{2/3}$) a stiffness difference of 2.5*$10^6 Hz^2$ $g^{2/3}$ could be distinguished with satisfactory accuracy by all experts (in eight of the ten groups or more), whereas only one of the experts was able to consistently detect stiffness differences of 1.5. The two other experts only detected this difference in about 50% of the cases.

In Fig. 3 the chance of tomatoes being accepted or rejected is plotted as a function of the average stiffness measured with the acoustic impulse-response technique. There was a discrepancy between the experts' rating (data not shown). Also the percentage of 'questionable' tomatoes was very high: on average 40% for tomatoes with a stiffness factor below 3.5*$10^6 Hz^2$ $g^{2/3}$ and 30% for tomatoes of higher stiffness factor (based on the experimental data). This illustrates the need for an objective measurement device for firmness determination. Tomatoes with a stiffness factor higher than 2.5* $10^6 Hz^2$ $g^{2/3}$ had 10% or less chance to be rejected without doubt. When the stiffness factor dropped below this value, the Fig. 3. The amount of tomatoes rejected: questioned: accepted
by auction experts as a function of the stiffness measured with the acoustic impulse-response technique amount of rejected tomatoes increased rapidly and reached 50% for a stiffness factor of about 2.0*$10^6 Hz^2$ $g^{2/3}$

Galili and De Baerdemaeker (1996) found that experts considered tomatoes with a stiffness factor of less than 3*$10^6 Hz^2$ $g^{2/3}$ as too soft, while Varlan et al. (1996) showed that consumers preferred tomatoes with a minimum stiffness factor of 2.2*$10^6 Hz^2$ $g^{2/3}$

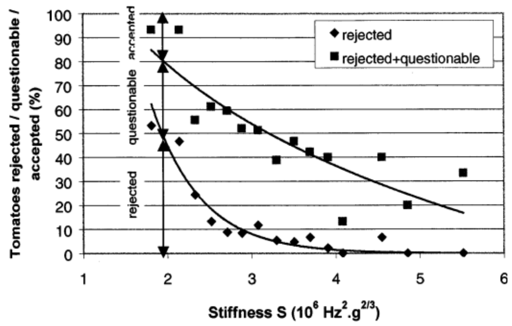

Fig. 3. The amount of tomatoes rejected :questioned: accepted by auction experts as a function of the stiffness measured wit the acoustic impulse-response technique.

Experiment 3: *change in firmness of tomatoes during storage*

We checked whether the above model (2) could be used for a group of tomatoes from the same segment, grower and season, with the same colour at harvest and stored under the same conditions. The use of an iterative procedure to find the best non-linear least squares fit resulted in exponential models. The model parameters (initial stiffness and deterioration rate) of the different experimental groups were estimated. Comparison of the deterioration rates of different tomatoes within each group confirmed that firmness at harvest did not influence the deterioration rate significantly (*P*B0.05). The model (2) was also compared with an exponential model with constant term *S*_. This second model was introduced in order to take into account that the stiffness factor at *t*__ cannot equal zero.

Table 1
Repeatability *t* and accuracy *R* of firmness *S* and expert scores E

Lowestimate:	High		estimate:	
	$s_b = G/4$		$s_b = G/6$	
	t^a	R^b	t^a	R^a
Firmness (*S*) 0.936	0.779	0.956	0.701	
Expert 0.935 scores (*E*)	0.776	0.955	0.697	

CONCLUSION

Although we can determine the maturity of the agricultural products manually by tapping it, it takes *more time* and *many labours* for determining the large quantity of agricultural products. In addition to it, the determination will change for each and every person as per their thoughts. Hence the ***acoustic resonance technique, non-destructive method for quality evaluation*** the maturity and defects in the agricultural products can be determined *accurately in short time*.

FUTURE ENCHANCEMENTS

- The developed instrument is used only to determine the firmness of the agricultural products of *smaller size*. It is not applicable for larger fruits or vegetables. Hence a system must be developed for agricultural products of larger size.
- By using this smart office analyzer the grade has to be selected by comparing the frequencies with pre-defined frequencies manually. A software for *automatic grading* has to be developed.

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