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Monitoring Firmness Evolution of Round Eggplant (Solanum Melongena L.) During Storage by Non-Destructive Acoustic Method

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ABSTRACT

A few years ago, the inspection of impact quality and maturity for fruits and vegetables by using different methods and devices has become the focus of extremely intensive research. Firmness is one of the major factors contributing to the quality of eggplant fruit. There are a lot of tests, and experiments have been introduced and done to evaluate the effects of their impact on agricultural products using high techniques such as vibration (acoustic, ultrasonic and sonic response). This research was conducted in order to help the small companies and farmers to get an inexpensive way to improve their eggplant quality. In this research, the firmness of eggplant fruit was monitored by using the non-destructive acoustic method. One device and one measurement system were developed in order to run the experiment for the acoustic method. This technique provides a stiffness factor S, based on the time interval and the mass of intact fruit. The firmness of eggplant fruit was monitored for 10 days until the condition of room temperature. Besides that, the experiment by using the texture analyzer also was held to measure the hardness of the eggplant during the storage period. The comparison between the acoustic method and the texture analyzer was validated through the series of test. At the end, result from this research showed that the firmness of eggplants was decreased by the day increase. The firmness and hardness of the eggplant also were related according to the correlation between them.

Keywords: Firmness, Hardness, Eggplant, Acoustics.

1. INTRODUCTION

The increase in demand for a high-quality agricultural product market has become one of the global issues. In order to ensure the products meet consumer expectations, quality of products become important for monitoring and evaluating the food products. This global issue becomes the reason for the development of optical, acoustic and mechanical sensors that determine the fruit's quality.

Usually, consumers judge the quality of fresh fruit by their firmness, colour and taste. These criterions will enable the consumers to know about the lifespan of the fruit or vegetables by biting, chewing or pushing a thumb into a flesh. It is very important to know the lifespan of any food products because it can measure the quality and food safety. Because of that, the fruit packing companies need to play an important role in order to measure these quality variables. Firmness level is one of the criteria to sort fresh fruit. This criterion has been known for many years. To measure the firmness of the fruit, there are many non-destructive methods have been introduced.

Many methods have become sensitive to the physical attribute which is a mechanical (acoustic and impact response, the force-deformation curve, ultrasonic methods), an electromagnetic (nuclear magnetic resonance), an optical (near-infrared spectroscopy, visual methods) and a chemical property (electronic nose) (Macrelli *et al.*, 2013). For example, several techniques and methodology have been developed to measure the firmness. One of them is Magnes-Taylor firmness tester used in storage application of post-harvest and for the destructive test (optical, magnetic resonance and ultrasonic) (Nourain, 2012). Between those methods, there are advantages and disadvantages. Most of the above methods are expensive. The tools that were used for every method might be too expensive for small companies. So, the certain company will find a method with a lower cost. This is because of reliable and low-cost real-time firmness evaluation techniques will give the advantages in helping the modern industrial procedures for sorting fruits and vegetables.

Acoustic is an interesting technique to assess the quality of food products. This is because of it fasts, reliable, economic and non-destructive. The advantage of impact acoustic is compatible with several types of transducers and analysis technique. For instance, according to Jiménez *et al*., (2012), in order to extract different time and frequency-domain characteristics, an impact sound of falling nuts were acquired with a microphone. Instrumental acoustic methods are becoming popular in determining the quality of agricultural and food products because of such benefits and advantages.

Nowadays, the demand for high-quality standards of agricultural product market requires a non-destructive technique that comes with the advantages of inexpensive, rapid and reliable assessment of fruit properties. Eggplant is one of the quality fruits that had a good potential to be exported to another country. In Malaysia, eggplant has not widely been commercialized about its specialty, which can be used in a lot of ways such as the food product and medicinal. Eggplant can give a lot of benefit to people or country in economical, especially.

Eggplant (*Solanum Melongena*. L) is one of the vegetables planted in South East Asian and has been commercially cultivated in most parts around the world. According to Fan *et al*., (2016), the annual production of the worldwide eggplant is around 58 million tons in 2013. It is a fruit which can be planted anytime and can be harvested at 11 or 12 weeks after being planted. These eggplants have to differ in many varieties, which are in terms of size and shape that are grown throughout the world. Eggplant has many used against the people who, for instance, are for cooking and medicinal. In South Asia, the eggplants are being used in cooking the curry and also for many different kinds of dishes (Farming, 2016). These eggplants can be easily marketed because there is good demand in local vegetable markets. The commercial cultivation of eggplant yields a good profit. Basically, Burma region is the origin of eggplant crop and then; it is distributed in South and South-East Asia, Southern Europe, China and Japan (Farming, 2016).

Firmness is important criteria in the determination of harvest time, fruit and vegetable maturity, and quality grade of a fruit or vegetable. Measurement of fruit firmness is a tedious and complicated job. This is certainly true for fruits whose colour has no direct correlation with its level of firmness, maturity or ripeness Bhosale & Sundaram, (2014). A human can determine the fruit's firmness by its own perceptions and skills, but it has become beyond practical for the larger quantity inspection. The accurate automatic classification for firmness of fruit may be advantageous for the agricultural industry, consumers in markets.

For many years, firmness has become one of the criteria for sorting the fresh fruits or vegetables. The methods used were including, biting and chewing, squeezing between the fingers or hands, pushing a thumb into a flesh, and the penetrometer method which is referred as a Magness-Taylor (Wang, Teng, & Yu, 2006). Non-destructive methods have been sought to quickly measure individual fruit for sorting by firmness because of its destructive nature of these tests and an increasing emphasis on quality.

The objective of the work reported here was to investigate the feasibility of using the non-destructive acoustic method as a mean to monitor the firmness for round eggplant for small companies and farmers to get an inexpensive way to improve their eggplant quality.

2. METHODOLOGY

Eggplants (*Solanum Melongena* L.) were collected from the local market at different locations according to their size and common use. Fifteen eggplants were chosen depending on their outward appearances at same maturity stage. The eggplants were stored at a room temperature at a temperature of 27°C and 85% relative humidity with a shelter from direct sunlight. Five of the eggplants were tested daily for ten days using an acoustic system to determine the time elapsed and other acoustic parameters, while other eggplants were tested using the texture analyzer to identify hardness.

2.1 Measurement System

A schematic diagram in Figure 1 shows the flow of acoustic measurement. A buzzer generates the pulsed sound which is a one-half wavelength at 1 kHz. A small speaker was attached to the eggplant surface and at the other side, there was a small contact microphone attached. A small amount of clay will be directly installed in between the buzzer and sample in order to facilitate the sound transfer. A data-acquisition module (Arduino) monitors the transmitted wave and displayed it together with the imposed wave. To estimate the elapsed time for sound transmission (Δt) through the fruit and the extent wave displacement was used. The elapsed time for sound transmission is the time difference between the first peak of received sound waves, and the peaks of pulsed sound generated.

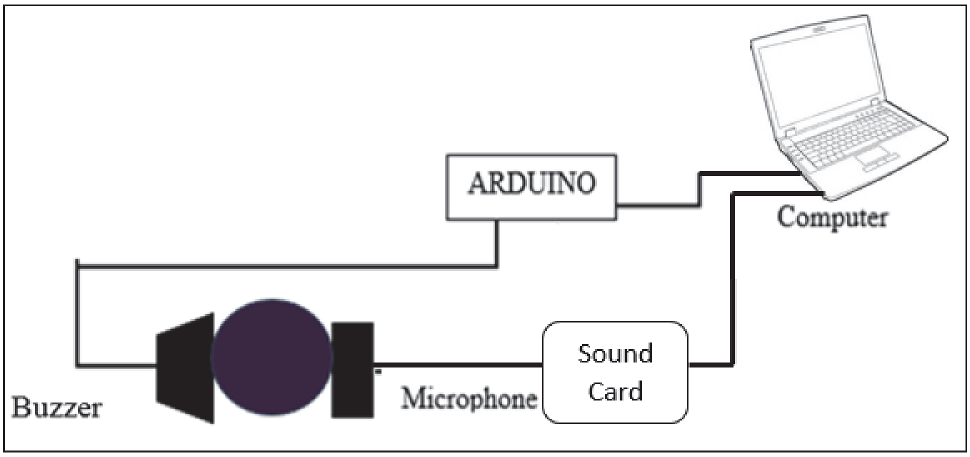

Figure 1. Schematic Diagram of Acoustic Method.

According to Macrelli *et al.,*(2013), they had done an experiment by using the four measurement positions, respectively at 0^o, 90^o, 180^o and 270^o around the equator of the sample. For this experiment, the eggplant also was measured in the same measurement positions respectively. For each position of the fruit, the elapsed time Δt (s) are obtained was used to measure the stiffness indexes. For measuring the stiffness indexes, there must be an equation. The equation that was used is:

$$S = \frac{m}{\Delta t^2 r} \tag{1}$$

S = Stiffness
m = mass
Δt = time elapsed
r = radius

2.2 Measurement System

Texture analyzer (Figure 2) is one of the equipment that can be used to measure the firmness of fruit/vegetables. In this project, texture analyzer was used as a prove measurement to validate the measurement of eggplant's firmness. So, in this project, there was an experiment to measure the firmness of the eggplant by using the texture analyzer to prevent erroneous assessment. Texture analyzer has been known as one of the destructive methods. It performs it a test by applying controlled forces to the product and then record the response to the product in form of force, time and deformation.

Figure 2. CT3 Texture Analyzer.

For the texture analyzer, the test on eggplant's firmness was conducted at standard depths and speeds of penetration. This method will ensure accurate and repeatable results. In this method, the texture analyzer gave a single punch to every eggplant in order to measure the firmness of each eggplant. After that, the measurement that was taken was sent to the computer that ran the control software. The measurement that has been taken was shown as a graph which has been called as firmness curves.

3. RESULTS AND DISCUSSION

Table 1 shows typical data of stiffness level of eggplants for 10 days. All the data that had been saved with the excel file has been used to calculate the stiffness of the eggplant during the storage period. The sample of calculation for the stiffness is shown below. Meanwhile, Table 1 presents the data on the stiffness value for all five eggplants for 10 days. From the table, the stiffness value for all the eggplants was decreased by the day increased. For example, the value of the stiffness for eggplant 1 was 463.129 kg/ms^2 at the beginning and then continuously dropped into 167.308 kg/ms^2 for the day 10. This is similar to the experiment done by Vursavus *et al*., (2015) which show the same trend where the stiffness was a decrease in the day increase.

Table 1 Data of the stiffness value for 5 eggplants in 10 days

Days	Stiffness of Samples (kg/ms^2)				
	1	2	3	4	5
1	463.129	378.402	568.231	508.420	736.409
2	445.242	330.708	495.925	371.754	463.685
3	430.195	293.255	476.692	305.948	459.916
4	341.580	251.138	246.743	264.613	282.328
5	257.708	246.291	228.996	249.310	277.286
6	222.965	218.252	231.025	210.661	240.242
7	213.878	216.637	221.931	197.691	225.657
8	190.478	198.898	216.990	181.397	213.595
9	187.874	193.967	202.790	177.034	210.760
10	167.308	188.197	170.747	177.249	180.113

From the Table 1, the graph of stiffness versus days for five eggplants has been plotted as shown in Figure 3. The presented graph shows that the stiffness was a decrease in the day increase. Stiffness for eggplant four shows the highest value in day 1 and the least is eggplant 1. The difference in the value of the stiffness occurs because of the properties of each eggplant is not same between them. Even though the eggplants were bought from the same place and species, the properties are different. However, the trend is still the same as a previous study by another researcher. The same trend has been proved by Bhosale & Sundaram (2014) which used the apple fruit in their experiment.

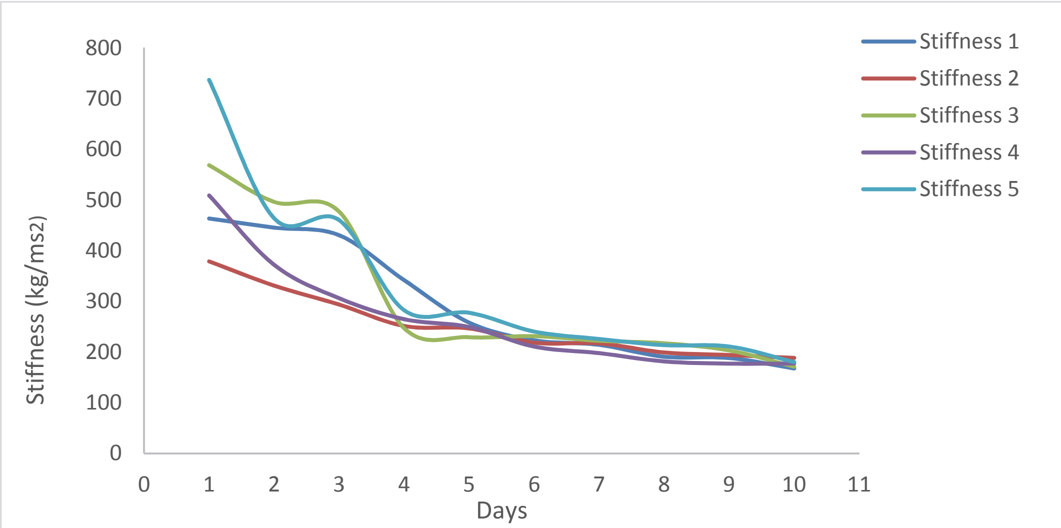

Figure 3. CT3 Texture Analyser.

In Figure 4, it shows the logarithmic regression between stiffness and days for the eggplant. From this logarithmic regression analysis, the R2 value is 0.9705 which are the best fit for this relationship between stiffness and days. The correlation between stiffness and days was expressed in $y = -159.9 \ln(x) + 530.17$. It can be established that the stiffness of the eggplant decrease as the days increase.

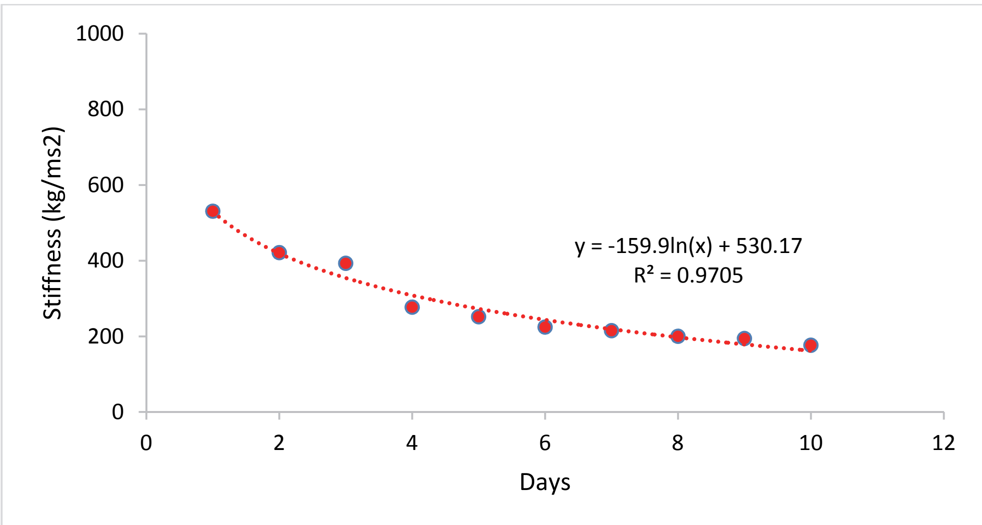

Figure 4. Correlation between stiffness and days.

3.1 Effect of Hardness to Days

From all the graphs and result that came from the texture analyzer, the graph of the hardness versus days has been plotted as shown in Figure 5. The graph shows the decrement in the values of hardness as the days increase. The value of hardness that has been plotted is the average between two eggplants per day.

According to the graph, the value of hardness for the day first of experiment is 1644 g meanwhile on the last day of the experiment, the day value of hardness was decreased to 1433 g. This situation might occur due to the water loss in the eggplant. This trend is similar to the experiment that was conducted by Yaman & Köse, (2015) which also used the eggplants as the materials.

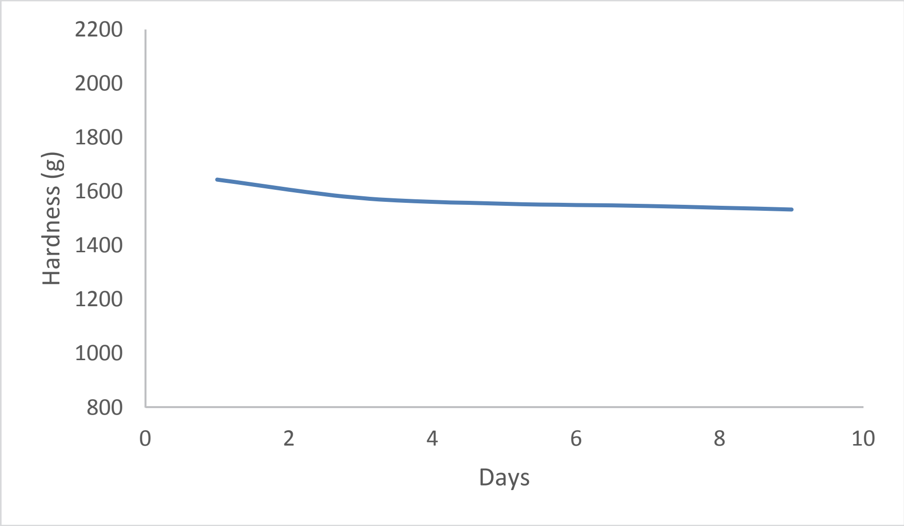

Figure 5. Graph of hardness versus days of the eggplant.

Meanwhile, Figure 6 shows the logarithmic regression between the hardness and days. From this regression, the R^2 value is 0.9808 which is the best fit for the relationship between hardness and days. The correlation between hardness and days can be expressed in $y = -49.94\ln(x) + 1639$ equation. It can be established that, when the hardness will decrease when the day increase.

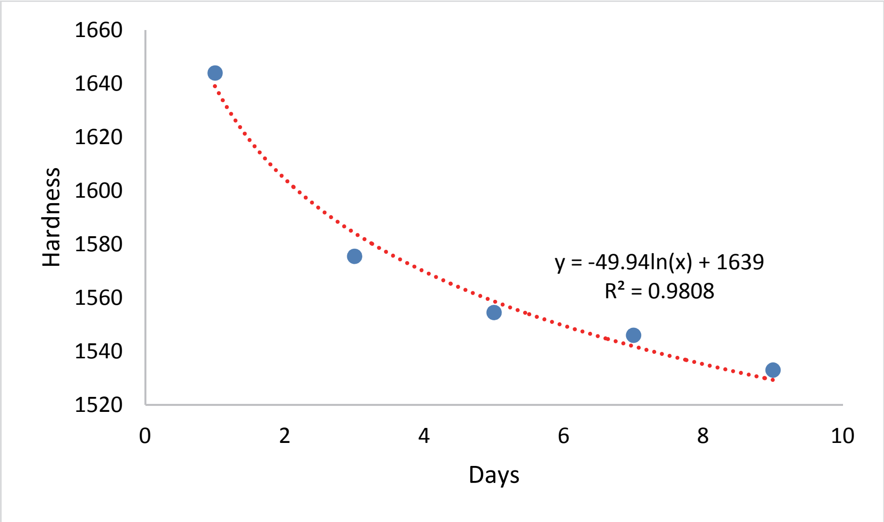

Figure 6. Correlation between hardness and days.

3.2 Correlation between Stiffness and Hardness

In this experiment, the correlation graph between stiffness and hardness has been plotted in order to describe the linear relationship between these two continuous variables. From the graph in Figure 7, the value of R^2 (0.9408), which is greater than 0. This means that the two variables are positively correlated and as stiffness values increase, the hardness value will also increase.

From the graph, the lowest values for stiffness and hardness are 530.92 kg/ms^2 and 1644 g. Meanwhile; the largest values for stiffness and hardness are 194.485 kg/ms^2 and 1533 g. The correlation between the stiffness and hardness of the eggplant was expressed in y = 0.2985x + 1475.9 equation. According to the value of R^2, it is close to 1. The closer the R^2 to 1, the better is the fit. So, it can be established that the graph is a better fit.

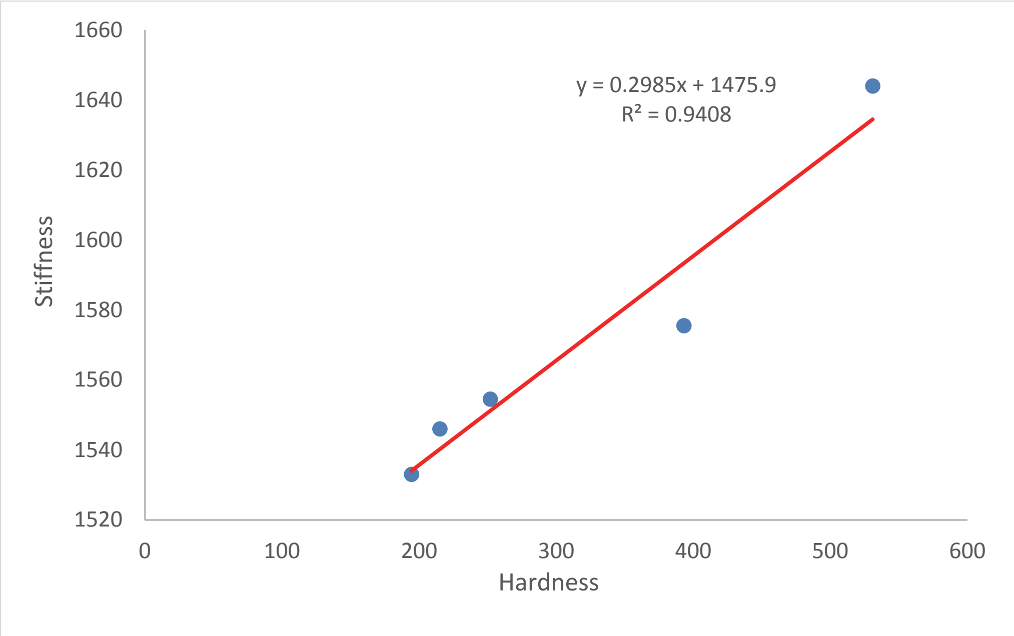

Figure 7. Correlation between stiffness and hardness.

4. CONCLUSION

The evolutions of hardness and stiffness were assessed from the experiment. Both stiffness and hardness showed the same trends, where the increase in days resulted in the decline of stiffness and firmness of the eggplant. At the end, the correlation between stiffness and hardness over the storage period was analyzed. It has been shown that the stiffness and hardness have a linear relationship. The stiffness values are increasing proportionally with the hardness. The correlation between stiffness and hardness of the eggplants was expressed in y = 0.2985x + 1475.9 equation. The value of the R^2 for this correlation was 0.9408.

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