Monitoring of Stiffness Estimation for Tomato During Storage Period

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Abstract. The quality assessment through stiffness or firmness is widely used to identify the maturity of fruits and vegetables. Most of assessment method are destructive and no cost effective. This study was done to develop a stiffness estimation for tomato during storage period by using acoustics method. This project involved the usage of modern tools such as Arduino and LabVIEW where both of them were used to controls and regulate the data collected from a buzzer that produced sinusoidal sound wave. The time taken for the sound wave to reach the microphone were recorded as it was considered as the important factor in determining the stiffness factor, S, alongside the changing mass and diameter of the tomato during its storage period. At the end of the project, it was shown that the stiffness value of the tomato decreases in hand as the day progress. Furthermore, the correlation of the parameters was also calculated in which R² value between stiffness and weight was finalized at 0.8993, with equation of y = 379.45x – 40.321. The findings had successfully proved that the parameters involved in the research are greatly related.

1. Introduction

Tomato industry is an economically important crop species that is regarded as a promising study for the Agro-industrial sector in Malaysia. Due to its important, a lot of research regarding on agricultural sector had been done by researcher [1-16]. The increasing demand of a high-quality agriculture product is one of the global issues that are nowhere far distant from the market of our beloved country. In Malaysia, tomato industry is an economically important crop that is believed to be increasing in demands for it gives many benefits to the consumer. Tomato belongs to the Solanaceae family which are also known as nightshades. This family of flowering plants includes potato, pepper, eggplant, goji berries and other berries. With over than about hundreds of varieties of tomato, however, they are all represented by one species, Solanum lycopersicum. There are about literally hundreds of different of tomato varieties present throughout the whole world. A past study in the context of weight loss of the fruit can be seen in a research done by Javanmardi and Kubota [17], where it was shown that the weight loss of tomato is much higher in numbers when kept at room temperature than in low temperature during 7 days of storage period. One of the possible reason is due to a significant rate of transpiration in room temperature compared to lower temperature as this has a significant effect on the weight loss of tomato.

The quality assessment through stiffness or firmness is one of the traditional methods regarded as the simplest way to identify the maturity of fruits and vegetables. Stiffness or firmness of fruits depends
on its physical structure as well as how the changes of its cell turgor [11]. Stiffness of tomato can be estimated by non-destructive method. This can be done through an acoustic probing where amplitude of the transmitted signal from the probe is investigated throughout the storage period of the tomato while it matures [12-13]. However, the limitation of this study is that it was founded to be inaccurate in detail analysis. The transmitted signals were found to be decreasing in their amplitude with storage days. The reason is told to be probably due to the variation happen on the surface firmness of the tomato [13]. Acoustic response in the freshness estimation for tomato is an aspiring project as the technique could be adopted to more various fruits and vegetables [14-16]. In this research studies, stiffness is set as the main parameter calculated that acts as the findings from the acoustic response done to the sample fruit tomato.

2. Procedure

2.1. Fruit preparation/selection

In this study, about ten tomatoes from the same variety was bought locally source from a near determined supermarket. The tomatoes that were selected as the samples of the experiment had a similar range of weight and spherically shape in order to minimize any other factors that would affect the frequency response of the acoustic system. The initial mass of each of the tomatoes was measured beforehand using a weighing balance. The experiment was conducted at Kolej Kediaman Tan Sri Aishah Ghani where all the sample tomatoes was stored in storage system designed with a control condition such as temperature and humidity. The temperature and humidity was set to be at about the value of 26ºC and more than 50% respectively. The reason for this chosen condition was to maintain its post-harvest quality where it was regarded as an optimum temperature and humidity [18] but still logical in way that it would not stress out the tomato. Both of the stated condition were controlled automated by a microcontroller that control the environment based from the input of temperature and humidity sensor. Tomato is said to be best placed in an area where the humidity ranges from 45% up to 100%. Apart from that, the system was also placed in an area that can be said as dark (or at least minimal direct sunlight).

2.2. Design of measurement system

Figure 1 shows the schematic setup of the measurement system. The measurement system had a function that was to acquire and collect the time response from the tomato after being projected with a sound source. The system was based on a model developed by previous researcher [13,19]. This project was aided with several instruments and equipment such as the microphone, Arduino Uno, control circuit, and a personal computer. Arduino controlled the sound waves produced by the buzzer, in which the waves was then travel through the fruit sample, which was tomato. These sound waves were set at 1000 Hz where it went passed through the sample and transmitted to microphone, a sound collector device in this particular system. The distance between microphone and buzzer were fixed at a distant of 6.5 cm apart. The sound waves were received by a sound card which was connected with the computer. The computer was then analysed the data gathered and determine the results of the experiment based on the time response of the collected sound waves.
2.3. Calibration of measurement system

Thereby, sound waves of determined frequency will be projected to the microphone and the elapsed time from the initial measurement system will be compared with the actual time response of the sound wave that involved tomato samples. 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.

2.4. Fruit measurement

The solution was carried out with a frequency response where the stiffness of the tomato can be calculated through the elapsed time measure. For the proposed measurement system, the frequency of the tomato will be conducted for 10 days in which the result of the amplitude will be collected. The sound measurement was done at near midnight for the whole period of the experiment. The position of the impact orientation on the tomato, detected orientation by the microphone, impact velocity and impact material does not definitely affected the frequent dominancy [20,21]. Besides that, Macrelli et al. [22] had done an experiment where four positions respectively of at 0º, 90 º, 180 º and 270º was measured around the equator of the sample. For this experiment, the tomato was only measured in the same measurement positions as to reduce any measuring time thus decreasing the scope of the data collection process.

2.5. Weight measurement

In order to relate and find the acoustic correlations between stiffness and weight, several parameters of the sample were measured beforehand. The first one was the diameter of the tomato, which was measured with a simple ruler at the same diameter line of the tomato. Then, the mass of the tomato which was measured and collected with a weighing balance. Both of this measurement had been done throughout the duration of the experiment, strictly after the acoustic measurement finished. The stiffness of the sample tomato was calculated by obtaining its mass, radius, and time elapsed during the acoustic measurement. The stiffness value was calculated by the following formula:

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

3. Result and Discussion

3.1. Physical properties of tomato

The average mass and diameter by day for the 10 tomatoes are presented in Figure 2. Both of the physical properties show decrease trend during the storage period. Standard deviation of the data are huge due to various size of tomatoes had been tested. The tomatoes exhibit reduction of mass at average 8.4%, which the average initial and final mass were 0.119 kg and 0.109 kg respectively. The mass reduction curve shows inverse exponential-liked trend with the mass reduction between days getting
smaller as day increase, refer to slope gradient. Furthermore, the diameter reduction shows the same decreasing but with exponential-liked trend. The slope trend was getting steeper as number of days increase. The evolution of mass and diameter explained the continuous respiration process in the post-harvest of the tomato after abscission as well the water loss by the tomato due to the transpiration process [23]. Study by Khandaker et al [25] showed the similar decreasing trend in fruit physical properties, which continuous decrease in weight an diameter of the fruit as days increase. The physical properties evolution directly was effecting the value of the stiffness of the tomatoes [19], [26].

![Figure 2](image.png)

**Figure 2.** Evolution of the average mass and diameter by day for the 10 tomatoes.

3.2. **Stiffness effect during storage period**

Figure 3 shows the average stiffness evaluation for the 10 tomatoes for 10 days. The stiffness was extremely reduce with first to third day before gradually decrease until the tenth day. The phenomena explained by change of internal physical properties of the tomato due to degradation, known as bruising effect [27]. The bruising effect cause change physical density for internal tomato describes the mass of a substance per volume [28]. The density of a medium is the factor that affects the speed of sound. The similar trend was shown by the previous studies by Ketelaere et al. [29] and Bhosale et. al [30], where the stiffness value decreases as the day increases.
In order to compare analyze the sensitivity stiffness and for storage days to the tomato, the regression analysis between the data are plotted with regression in F. From the following logarithmic analysis, the $R^2$ value is calculated to be 0.9775, which is seen as a best fit of a relationship between those two data. The relation between stiffness and days was expressed as $y = 5.929x^{-0.57}$. It can be said that the stiffness of the tomato decreases as the day progresses.

![Figure 3. Evolution of the stiffness by day for the 10 tomatoes.](image)

**3.3. Correlation between stiffness and mass**

In reviewing the data gathered from the experiment done, a correlation graph has been plotted which illustrates on the linear relationship between two continuous variables which are of stiffness and mass of the tomato in Figure 5. The graph shown in the following analysis of Figure 5, the value of $R^2$ is 0.8993 can be seen to be nearing to the value of 1. This shows that the model fits with the data as the data plotted are about 80% close to the fitted regression line. Consequently, it can be said that as the stiffness increases, the mass will also increase. The equation for the relationship is discerned to be $y = 379.45x - 40.321$. 

![Figure 4. Correlation between stiffness and days.](image)
4. Conclusion

The evolution of the stiffness values was seen from the analysis done in this experiment, and generally, the trends illustrated that the stiffness decreases as the day progress for the tomato during its storage period. At the end of the research, the correlation between the stiffness of the tomato with its mass over the whole days of storage period had been analysed. From the investigation, the properties have a positive linear relationship between each other where the stiffness increases as the mass increase. The correlation between both the stiffness and the mass of the tomato can be expressed in the equation $y = 379.45x - 40.321$, with $R^2$ value of 0.8993.

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