

Non Destructive Determination of Soursop Firmness and Sweetness With Ultrasonic Method

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Article History :

Received : 9 May 2022

Received in revised form : 7 June 2022

Accepted : 9 June 2022

Keywords :

Attenuation coefficient,

Ripeness,

Soursop,

Ultrasonic,

Velocity

ABSTRACT

Firmness and sweetness are parameters that significantly affect the quality of soursop fruit. This study aims to examine the application of the ultrasonic method to nondestructively determine the quality (firmness and sweetness) of soursop fruit. Measurements were carried out using three different ripeness levels of soursop fruit, namely unripe, ripe, and overripe. Samples were measured using an ultrasonic wave measurement system with a frequency of 50 kHz and followed by measurements of the physicochemical properties such as firmness and total soluble solid (TSS) of the fruit. The results showed that the ultrasonic wave velocity of soursop fruit at three levels of ripeness ranged from 169.03–278.31 m/s, while the attenuation coefficient ranged from 9.11–19.94 dB/m. The firmness values, total soluble solids, and density were 1.37–61.59 N, 5.73–17.93 °Brix, and 1014.77–1630.13 kg/m³, respectively. There were significant correlations between ultrasonic parameters, firmness, and TSS. Two linear regression equations were developed for classifying the level of firmness and sweetness, respectively based on ultrasonic wave velocity parameters. The equations successfully classified three level of firmness and sweetness of soursop fruit with the accuracy of 100% and 95%, respectively. Thus the ultrasonic wave velocity parameter could be used in classifying soursop fruit based on the level of firmness and sweetness.

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1. INTRODUCTION

One of the agricultural sub-sectors widely developed in Indonesia is horticulture. One of the leading horticultural commodities that farmers in Indonesia widely cultivate is fruit. It is because fruit commodities have a fairly high economic value. In addition, fruit commodities also have a relatively broad market range, both in the national and international markets. One of the fruits that are quite in demand and consumed every year is soursop. Soursop fruit production in Indonesia in the last five years (2015-2019) increase about 20% from 58,994 tons to 70,729 tons (BPS, 2022).

The characteristics of soursop fruit that consumers prefer are fresh and sweet fruit, medium fruit texture or firmness level, and even fruit skin colour (yellowish-green). Farmers generally measure the ripening level of the fruit based on the age of harvest or the ripening stages. Another method is done subjectively, namely by looking at the size and colour visually based on the farmer's experience, causing the fruit quality to be varied and inconsistent with the internal quality. In addition, in determining the level of sweetness and firmness of soursop fruit, a destructive method is commonly applied using refractometer and rheometer. Therefore, a new evaluation method is needed to objectively and non-destructively determine the level of sweetness and firmness so that the fruit picked is suitable to consumer demand.

One of the non-destructive potential methods used to determine the level of sweetness and firmness in soursop fruit is ultrasonic. Ultrasonic wave is one of the mechanical waves that can propagate in dense solid or liquid media. Ultrasonic waves can penetrate the fruit without damaging it so that the parameters in soursop flesh can be identified. Ultrasonic method has been extensively studied to evaluate quality of agricultural products nondestructively, such as avocado (Mizrach *et al.*, 1989), potatoes (Cheng & Haugh, 1994), mango (Mizrach *et al.*, 1997), durian (Budiastra *et al.*, 1999, Haryanto *et al.*, 2001, Rejo *et al.*, 2001), mangosteen (Juansah *et al.*, 2006), rubber (Maspanger *et al.*, 2008), dragon fruit (Jamilah *et al.*, 2010), apple (Lee *et al.*, 2013), persimmon (Astiani *et al.*, 2016), and pineapple (Luketsi *et al.*, 2017). This study aims to determine the characteristics of ultrasonic parameters on soursop fruit at various levels of sweetness and firmness according to levels of fruit ripening, to determine the relationship between ultrasonic wave parameters (velocity and attenuation) with the level of sweetness and firmness of soursop fruit, and to classify the level of sweetness and firmness of soursop fruit based on ultrasonic wave parameters.

2. MATERIAL AND METHODS

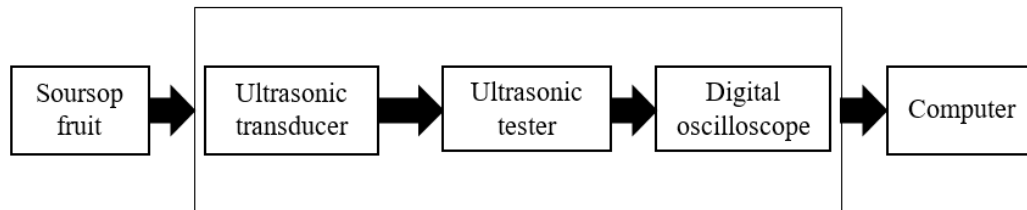
The ultrasonic wave measuring device used in this study was designed by Juansah *et al.* (2006). The set of devices includes an ultrasonic transmitting and receiving transducer made of piezoelectric material, a transducer holder equipped with a sample thickness gauge, a digital oscilloscope (ETC M621), an assembled ultrasonic tester (Juansah *et al.*, 2006), and a computer (PC). Other equipment used in this research is a rheometer model CR 500-DX and refractometer Atago PR 201. There are also callipers used to measure dimensions, digital scales to measure weight, knives, measuring cups, and distilled water.

The material used in this study was soursop fruit harvested from farmers' gardens at physiological maturity at 80 days after fruit set in Girijati Village, Purwosari District, Gunung Kidul Regency, Special Region of Yogyakarta. The sample taken for research had three different criteria of ripeness level. The unripe fruits was harvested fruit without storage treatment in room temperature, as the ripe and overripe fruits were harvested fruits with 4 days and 8 days of storage in room temperature of 25 °C, respectively. The number of each sample taken randomly is 20 out of 40 fruits so that the total number of analyzed samples is 60 fruits.

2.1. Measurement of Ultrasonic Wave Parameters

Measurement of ultrasonic wave parameters on soursop fruit was carried out using an ultrasonic wave measurement system (Juansah *et al.*, 2006). Measurement of the transmission characteristics of ultrasonic waves was based on ultrasonic frequency of

50 kHz. The information flow scheme for measuring ultrasonic waves on soursop is shown in Figure 1. The fruit was placed between transmitter and receiver transducer. The tip of the transducers was set up in contact to fruit surface. Ultrasonic tester generated pulse signal to transmitter transducer. Ultrasonic wave generated by transmitter transducer penetrated in the fruit, detected and converted to electric signal by receiver transducer. The signal from receiver transducer was then amplified by ultrasonic tester, converted to digital by a digital oscilloscope and recorded by a



computer.

Figure 1. Measurement scheme of ultrasonic wave parameters

2.2. Ultrasonic Wave Velocity Measurement

Ultrasonic wave velocity measurements both in air and on fruit are done by obtaining the wave travel time. Travel time measurement is done by taking the difference in electrical pulses from the transmitting circuit, which is connected directly to the oscilloscope to the electronic pulses of the receiving circuit. The measurement of travel time is the time obtained when the wave begins to be emitted by the transmitter until it enters the fruit. After the travel time measurement obtained, measurements were also performed for the diameter of the fruit and the distance between the transmitter and receiver when ultrasonic waves passed to get the velocity value. The velocity of ultrasonic waves after passing through air or fruit was calculated using the Equation 1.

$$v_u = \frac{s}{t}$$

(1)

where v_u is velocity of ultrasonic waves on the device (m/s), s is fruit diameter or distance between transmitter and receiver (m), and t is ultrasonic wave travel time (s).

The velocity of ultrasonic waves in the air is 340 m/s. The ultrasonic velocity value in air obtained through measurement system was calibrated with the actual ultrasonic velocity value in air. Then the constant value (c) obtained is used to find the actual velocity of ultrasonic waves on soursop fruit. The velocity of ultrasonic waves on the fruit can be calculated using Equation 2.

$$v_{act} = v_u \cdot c \quad (2)$$

where v_{act} is actual ultrasonic wave velocity on fruit (m/s) and c is constant calibration result.

2.3. Attenuation Coefficient Measurement

Wave attenuation was measured by observing the decrease in the amplitude of the ultrasonic wave after passing through the soursop fruit. The results of the amplitude measurement can be described as a function of the distance travelled. According to

Sutrisno *et al.* (2017), the value of the attenuation coefficient can be calculated using the Equation 3.

$$\alpha = \frac{1}{x} \left[\ln \frac{A_0}{A_x} \right] \quad (3)$$

where α is attenuation coefficient (dB/m), x is distance traveled by the wave (m), A_0 is initial wave amplitude (volts), and A_x is amplitude of the wave after traveling a distance x (volts).

2.4. Fruit Density Measurement

Measurement of fruit density consists of measuring fruit mass using an analytical balance and fruit volume using the water displacement method. The density of soursop fruit can also be calculated using the data from fruit mass and volume measurement using Equation 4.

$$\rho = \frac{m}{V} \quad (4)$$

where ρ is density of soursop fruit (kg/m³), m is mass of soursop fruit (kg), and V is volume of soursop fruit (m³).

2.5. Fruit Firmness Measurement

The level of firmness on soursop fruit can be measured using a rheometer brand Sun Rheo Meter type CR 500-DX. This tool can be set in mode conditions: 01; R/H (hold): 9.50 mm; P/T (press): 10mm/m; Rep.1: 1 x 0 h; Max 10 kg. Using probe number 38 ($\varnothing = 5$ mm). As for the stabbing point, it is done at three different stabbing points on the fruit. The measurement results of the firmness of the fruit flesh will be read automatically on the pointer scale on the rheometer in kilogram-force units.

2.6. Measurement of Total Soluble Solid of Soursop Fruit

Measurement of TSS (Total Soluble Solid) or the level of sweetness in soursop fruit was carried out using a refractometer. Soursop fruit that has been split then the flesh is extracted. After that, the soursop flesh is mashed and squeezed to get the juice. The juice from the resulting soursop fruit is then placed on the lens of the refractometer. After pressing the start button, the TSS value will automatically appear on the refractometer screen. The TSS value is expressed in °Brix units. After using the instrument, the lens on the refractometer must be cleaned first using distilled water and calibrated until the value read on the refractometer screen shows the number 0.

2.7. Data Analysis

Ultrasonic wave characteristics data (velocity and attenuation coefficient) and measured parameters (sweetness and firmness) on soursop fruit were analyzed using analysis of variance (ANOVA) and Tukey's HSD (honest significance test) at a test level of 5% using SPSS 22 software. In addition, correlation regression analysis was also carried out using a linear regression graph scatter plot in Microsoft Excel 2013. The method used to predict the level of sweetness and firmness of soursop fruit based on ultrasonic wave parameters is a linear regression analysis as shown in Equation 5.

$$y = a + b x \quad (5)$$

where y is dependent variable or response (sweetness and firmness), a is constant, b is slope or coefficient estimate, and x is independent variables or predictors (wave

velocity and attenuation coefficient).

3. RESULTS AND DISCUSSION

3.1. Physicochemical Properties of Soursop Fruit at Three Levels of Ripening

Based on the pattern of respiration rate, soursop is categorized in climacteric fruit. The climacteric fruit ripening process will occur by itself or by ripening. During the ripening process, soursop fruit undergoes several changes both physically and chemically. Changes in the physicochemical properties of the soursop fruit can be measured destructively. This destructive measurement aims to know several characteristics, namely firmness and total soluble solids. The results of the measurement of the physicochemical properties of the soursop fruit is shown in Table 1.

Table 1. The average value of the physicochemical properties of soursop fruit at three levels of maturity

Physicochemical Properties of Soursop Fruit	Unripe Soursop Fruit	Ripe Soursop Fruit	Overripe Soursop Fruit
Firmness (N)	47,07 ± 6,70 a	11,74 ± 1,83 b	3,30 ± 1,43 c
TSS (°Brix)	6,99 ± 0,69 a	14,28 ± 1,94 b	16,27 ± 1,14 c
Density (kg/m ³)	1434,13 ± 94,41 a	1209,06 ± 94,45 b	1130,98 ± 97,87 c

The numbers in the same row followed by the same letter are not significantly different at the 5% test level.

3.1.1. Firmness

Fruit firmness is one of the physical parameters used to determine the level of fruit maturity. The older the fruit, the lower the fruit firmness. Softening of the fruit occurs due to damage or deterioration of cell structure, cell wall composition, and intracellular which is a biochemical process that involves the degradation of water-insoluble pectin (protopectin) into water-soluble pectin so that the cohesion power between cell walls decreases (Ali *et al.*, 2010).

Measurements were made at three points of the fruit; the top, middle, and bottom. The firmness values at three levels of ripeness tended to decrease along with the increase in the ripeness level of the fruit, as shown in Table 1. The firmness of soursop fruit at the three ripeness levels was significantly different. The average firmness value of unripe, ripe, and overripe soursop fruit was (47.07 ± 6.70) N, (11.74 ± 1.83) N, and (3.30 ± 1.43) N. This result indicates that appropriate packaging should be carried out especially for ripe and overripe fruit in short distance transportation to consumer.

3.1.2. Total Soluble Solids

Total soluble solids can be used as a parameter in determining the level of fruit ripeness. The higher the level, the total soluble solids value will also increase. That happens because during the ripening process, the fruit undergoes a breakdown of carbohydrates into sugar content. In unripe fruit, there are many carbohydrates stored in the form of starch which during the process of fruit towards maturity, the starch content will turn into sugar (Putri *et al.*, 2015). Amiarsi (2012) also stated that the value of the total soluble solids content was caused by the accumulation of glucose caused

by the faster hydrolysis of carbohydrates into glucose compounds compared to transforming glucose into energy and H₂O in the respiration process. Total soluble solids in unripe, ripe, and overripe soursop fruit were (6.99 ± 0.69) °Brix, (14.28 ± 1.94) °Brix, and (16.27 ± 1.14) °Brix. TSS of three ripeness level is significantly difference. As fruit ripen, TSS of soursop increased.

3.1.3. Density

The results of measurements and density calculations on underripe, ripe, and overripe soursop fruit were (1434.13 ± 94.41) kg/m³, (1209.06 ± 94.45) kg/m³, and (1130.98 ± 97.87) kg/m³. The results of data analysis with a 5% significant difference test showed that the fruit density for each ripeness level was significantly different. The decrease in the value of fruit density occurs due to a decrease in fruit weight during the storage period. The longer the fruit storage time, the higher the fruit weight loss (Kusumiyati *et al.*, 2018).

According to Nair & Singh (2003), weight loss also occurs due to the ongoing process of fruit respiration during the ripening process, resulting in water loss from the fruit flesh. The respiration rate will continue to increase during the fruit ripening process so that the fruit weight will also continue to decrease. Moreover, according to Sumiasih *et al.* (2016), weight loss in fruit occurs because the harvested fruit will continue to use its food reserves in the process of metabolic mechanism so that the food reserves in the fruit will continue to decrease because the fruit has been separated from the tree and also causes the process of fruit ripening faster.

3.2. Transmission Characteristics of Soursop Fruit Ultrasonic Waves

The characteristics of ultrasonic wave transmission that are commonly used are the attenuation coefficient and wave velocity. These two parameters are commonly used because they are influenced by the medium through which the ultrasonic waves pass. The properties of this medium have a relationship with the physicochemical properties of agricultural products. The measurement of wave velocity and attenuation coefficient at three levels of ripeness of soursop fruit are shown in Table 2.

Table 2. The average value of the ultrasonic wave transmission characteristics of soursop fruit at three levels of ripeness

Acoustic Properties of Waves	Unripe Soursop Fruit	Ripe Soursop Fruit	Overripe Soursop Fruit
Wave velocity (m/s)	257,87 ± 9,28 a	221,65 ± 7,71 b	188,74 ± 11,69 c
Attenuation coefficient (dB/m)	12,98 ± 2,39 a	14,48 ± 1,50 b	17,66 ± 1,39 c

The numbers in the same row followed by the same letter are not significantly different at the 5% test level.

3.2.1. Ultrasonic Wave Velocity

The average value of ultrasonic wave velocity on soursop fruit decreases as the fruit maturity level increases, as shown in Figure 5. The results of Tukey's HSD analysis on the data obtained results show a significant difference. The average velocity of ultrasonic waves obtained on unripe, ripe, and overripe soursop fruit, respectively, is (257.87 ± 9.28) m/s, (221.65 ± 7.71) m/s, and (188.74 ± 11.69) m/s.

The decrease in the value of the ultrasonic wave velocity is caused by the increasing level of fruit ripeness and the fruit's water content, which also increases. The reshuffle

of water-insoluble protopectin causes the increased water content in the fruit into water-soluble pectin, which will then be degraded to polygalacturonic acid, which produces water as a byproduct (Imaduddin *et al.*, 2017). According to Gooberman (1968), the transmission velocity of ultrasonic waves will be easier in a solid medium than in a liquid and gaseous medium.

3.2.2. Attenuation Coefficient

Inversely proportional to the velocity of ultrasonic waves, the average value of the attenuation coefficient on soursop fruit increases along with the increase in the level of fruit ripeness, as shown in Figure 6. The results of Tukey's HSD are significantly different on the attenuation coefficient of soursop fruit. The average attenuation coefficient obtained for unripe, ripe, and overripe soursop fruit, respectively, was $(12.98 \pm 2.39 \text{ dB/m})$, $(14.48 \pm 1.50) \text{ dB/m}$, and $(17.66 \pm 1.39) \text{ dB/m}$.

The attenuation coefficient is a quantity that describes the loss of wave energy due to passing through a certain medium. The attenuation coefficient depends on the type of medium. In a gas medium, the attenuation is large, in a liquid medium the attenuation is moderate, and in a solid medium the attenuation is small. The amount of energy absorption that occurs depends on the medium's physical characteristics through which it passes. In a solid medium, the absorption process of waves will often occur, characterized by a decrease in the amplitude of the wave (Trisnobudi, 2006).

3.3. Ultrasonic Wave and Physicochemical Properties of Soursop Fruit

3.3.1. Ultrasonic Wave Velocity and Fruit Firmness

The velocity of ultrasonic waves has a strong correlation with the firmness of soursop fruit. The graph of the correlation between the two parameters shows a positive trend which the higher the velocity of ultrasonic waves passing through the fruit indicates that the fruit firmness is also increasing, as shown in Figure 2. Based on the regression that has been carried out, a linear equation is formed with the correlation coefficient $r = 0.84$.

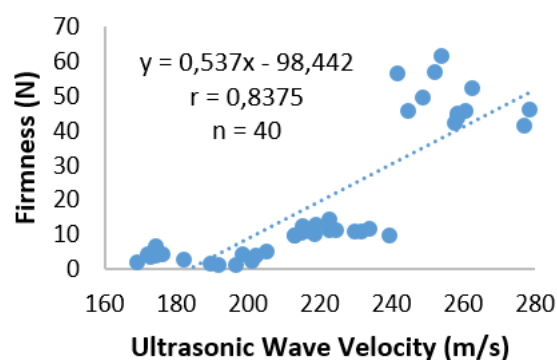


Figure 2. Correlation chart of ultrasonic wave velocity with of soursop fruit firmness

3.3.2. Ultrasonic Wave Velocity and Total Soluble Solids of Fruit

The correlation between ultrasonic wave velocity and total soluble solids of soursop fruit has a strong correlation (Figure 3). But the relationship between ultrasonic wave velocity and TSS of soursop is not a direct relationship since there is no interaction between wave velocity and TSS. The relationship was driven by the negative correlation between firmness and TSS. The resulting correlation coefficient value is $r = 0.81$.

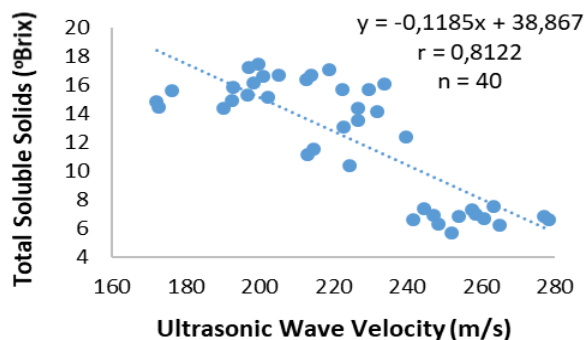


Figure 3. Correlation chart of ultrasonic wave velocity with TSS of soursop fruit

3.3.3. Ultrasonic Wave Velocity and Fruit Density

The velocity of ultrasonic waves has a fairly correlation with the density of soursop fruit (Figure 4). The value of the resulting correlation coefficient is $r = 0.68$.

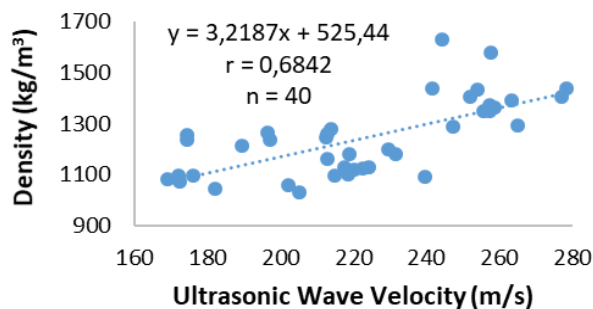


Figure 4. Correlation chart of ultrasonic wave velocity with soursop fruit density

3.3.4. Attenuation Coefficient and Fruit Firmness

The correlation between the attenuation coefficient and the firmness of soursop fruit shows a relatively fair correlatiof ultrasonic wave velocity (Figure 5).

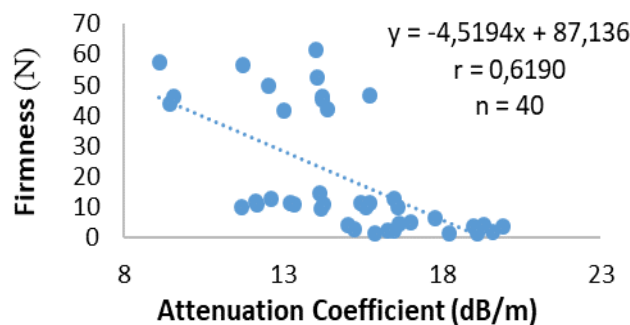


Figure 5. Correlation chart of attenuation coefficient with soursop fruit firmness

3.3.5. Attenuation Coefficient and Total Soluble Solids

The correlation coefficient between the attenuation coefficient and the total soluble solids content in soursop is $r = 0.64$ (Figure 6). This shows that there is a fairly correlation, but also lower than that of ultrasonic wave velocity.

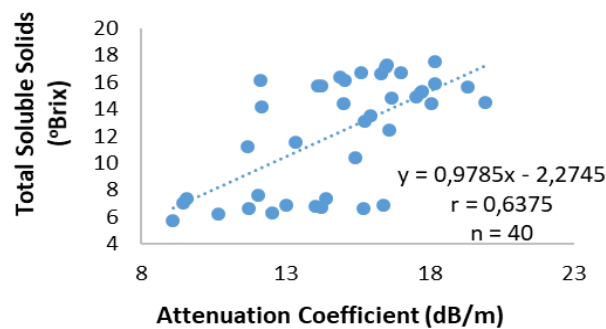


Figure 6. Correlation chart of attenuation coefficient with TSS of soursop fruit

3.3.6. Attenuation Coefficient and Fruit Density

The correlation between the attenuation coefficient and the density of soursop fruit shows a relatively fair correlation as presented in Figure 7. The value of the resulting correlation coefficient is $r = 0.50$.

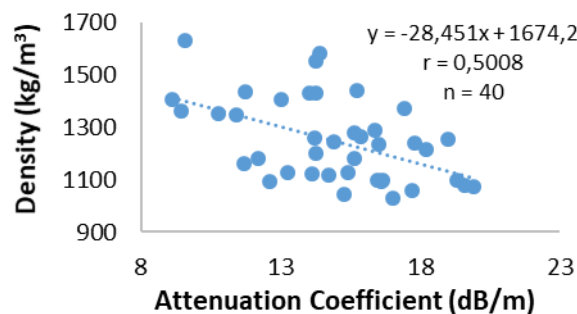


Figure 7. Correlation chart of attenuation coefficient with soursop fruit density

3.4. Classification of Firmness and Sweetness

The analysis of the correlation coefficient (r) value shows that the correlation between the velocity of ultrasonic waves with the level of sweetness and firmness of soursop fruit is stronger than the attenuation coefficient. Thus, the ultrasonic wave velocity is chosen to classify the level of firmness and sweetness in soursop fruit. Classifying the level of firmness and sweetness of soursop fruit using ultrasonic wave velocity parameters produces the following two equations.

$$y_1 = 0.537x - 98.442 \quad (6)$$

$$y_2 = -0.1185x + 38,867 \quad (7)$$

where y_1 is linear function of soursop firmness classifying (N), y_2 is linear function of soursop fruit sweetness level classifying (°Brix), and x is ultrasonic wave velocity (m/s).

The two linear functions above are to classify the level of firmness and sweetness based on the calibration results carried out on 40 data taken at random manually. Limiting the value of the level of firmness and sweetness is based on the average data from the direct test results at the time of the study and is based on several similar research results. Limiting the value of sweetness level is done by classifying which consists of three levels of classification, namely soursop fruit that is not sweet, slightly sweet, and sweet. Based on the results of research conducted by [Budiman et al. \(2017\)](#), soursop fruit has a high amount of sugar, which is 14°Brix, while according to [Fernandez et al. \(2017\)](#) soursop fruit has a degree of sweetness of 15-19 °Brix. There

are also three classification levels for soursop fruit firmness: hard, medium, and soft. The determination of the limits for the sweetness and firmness of soursop fruit can be seen in Table 3 and Table 4, which are based on the average data from the direct test results at the time of the study and based on several similar research results. As shown in Figures 8 and 9, unripe soursop fruit is characterized by high value of firmness and low level of sweetness. On the other hand, overripe fruit is characterized by high sweetness and low firmness.

Table 3. Soursop sweetness level limit

Level of Sweetness	Value of Sweetness (°Brix)
Not sweet	< 12
Slightly sweet	12–16
Sweet	> 16

Table 4. Soursop firmness level limit

Level of Firmness	Value of Firmness (N)
Hard	> 30
Medium	10–30
Soft	< 10

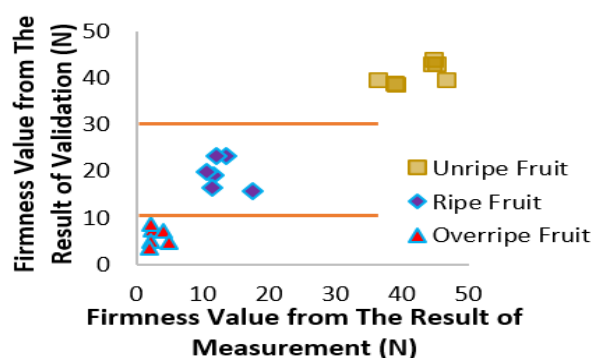


Figure 8. Soursop fruit firmness level chart

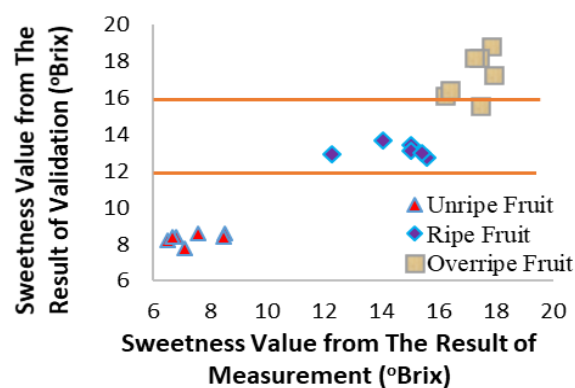


Figure 9. Soursop fruit sweetness level chart

The validation of the classifying levels of firmness and sweetness in Table 5 and Table 6 above were obtained using a linear regression function from 20 randomly selected samples. Data validation of 20 samples was carried out by comparing the data output value from linear function to the data value obtained from direct measurements on either a refractometer (for sweetness) or a rheometer (for firmness). From a total of 20 samples selected manually, the classifying results for hard, medium, and soft soursop fruit were 8, 6, and 6 fruits. After validation, the same amount is obtained as presented in Table 6 so that the accuracy obtained is 100%. Thus the resulting linear function (y_1) is excellent for classifying the level of firmness in soursop fruit. The results of grouping of 20 randomly selected samples for the fruit's sweetness level are not sweet, slightly sweet, and sweet are 7, 6, and 7 fruits. After validation, the number for each group was 7, 7, and 6 fruits, so that the accuracy obtained was 95%. Thus the resulting linear function (y_2) is also excellent for classifying the level of sweetness in soursop fruit.

Table 5. The results of the validation of three levels of firmness on soursop fruit

Level of Firmness	Hard	Medium	Soft	Total	Percent Accuracy (%)
Hard	8	0	0	8	100
Medium	0	6	0	6	100
Soft	0	0	6	6	100
Total	8	6	6	20	100*

*average value of classification accuracy (%) based on firmness level

Table 6. The results of the validation of three levels of sweetness on soursop fruit

Level of Sweetness	Not Sweet	Slightly Sweet	Sweet	Total	Percent Accuracy (%)
Not sweet	7	0	0	7	100
Slightly sweet	0	6	0	6	100
Sweet	0	1	6	7	86
Total	7	7	6	20	95**

**average value of classification accuracy (%) based on sweetness level

4. CONCLUSION

The ultrasonic wave velocity of soursop fruit at three levels of ripeness ranged from 169.03–278.31 m/s, while the attenuation coefficient ranged from 9.11–19.94 dB/m. The firmness values, density, and total soluble solids were 1.37–61.59 N, 1014.77–1630.13 kg/m³, and 5.73–17.93 °Brix, respectively. The velocity of ultrasonic waves has a very significant linear correlation with the firmness and total dissolved solids of soursop fruit with a correlation coefficient (r) of 0.84 and 0.81. Two linear regression equations has been developed for classifying the level of firmness and sweetness respectively based on ultrasonic wave velocity parameters. The equations successfully classified the three level of firmness and sweetness of soursop fruit with the accuracy of 100% and 95%, respectively. So the two functions obtained can be used in classifying soursop fruit based on the level of firmness and sweetness.

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