Determination of the Internal Damage of Purple Sweet Potatoes Non-Destructively Using Ultrasonic Wave Characteristics

Sutrisno¹ and Fauzi R M¹
¹Department of Mechanical and Biosystem Engineering, Bogor Agricultural University, Indonesia

E-mail: kensutrisno@yahoo.com

Abstract. This study aimed to analyze the ultrasonic wave characterization of Ayamurasaki purple sweet potatoes to predict the internal damage caused by weevil attack non-destructively. Sixty of health and 45 of infected purple sweet potatoes from farmers in Ciampea, Bogor were used for the experiment. Sample divided into 2 groups, the first group of 2/3 part was used in developing the model, and the second group of 1/3 part was used for validation. Ultrasonic wave characterization of purple sweet potatoes that harvested was tested using ultrasonic wave measurement apparatus with 50 KHz frequency. The result shows that the average wave velocity of infected purple sweet potatoes was 247.32 ms⁻¹ and Mo value was 19.45, while the wave velocity of healthy purple sweet potatoes was 235.15 ms⁻¹ and Mo value was 18.72. The average attenuation coefficient of infected purple sweet potatoes was 40.06 Np/m, while in health purple sweet potatoes was 42.69 Np/m. The result of discriminant analysis obtained a linear discriminant model that can distinctly separate between health and infected purple sweet potatoes. Accuracy of this grouping was high enough, around 85.71% so that the discriminant function can be used for grouping the health and infected purple sweet potatoes

1. Introduction
Purple sweet potato has a high economic value, is one of the main sources of prebiotic oligosaccharides and anthocyanin, and has great potential as a food industry in the country. One of the main obstacles of purple sweet potato cultivation is the pest attack (Clay fomicarius Fabricus), or in Indonesia well known as “lanas”. Lanas attack the purple sweet potatoes either during cultivation, transportation, or during storage. The lanas pest, known as the “boleng”, attacks the root epidermis, the stem and the outer surface of the tubers by making a hole that produces a toxic terpene and causing a bitter taste that cannot be consumed [1].

Sorting is an important step that done in postharvest handling of purple sweet potato to cut off the lanas pest attack. One of the obstacles to stop pest attack is the low application of technology by farmers during the sorting process, by mean that sorting is done manually, i.e., by looking at the outer surface of the tubers or by cutting both ends of the bulbs. Manual sorting is not appropriately applied to agricultural products, especially in purple sweet potatoes to detect pest attacks, as it is difficult to observe attacks on tuber meat from the surface so that the eggs or larvae of pests are carried along and cause further attacks during storage. Sorting destructively by cutting off both ends of the tubers also creates considerable losses in tuber meat and causes a reduction in income of farmers.

It is necessary to estimate the damage of purple sweet potatoes to effective pest attack without damaging the material. One method that can be applied is the use of ultrasonic waves, i.e., by observing
the acoustic properties of waves propagated in purple sweet potatoes, such as wave velocity, coefficient of attenuation, and zero moment power. Non-destructive test analysis using ultrasonic waves can be applied in the determination of the quality of fruits [2], such as detecting the ripeness level of sweet starfruit [3], knowing the physicochemical characteristics of dragon fruits [4], detecting the damage of ‘Arumanis’ mango due to the fruit fly [5], and predicting pest attack on “Cilembu” sweet potato [6]. Furthermore, [7] states that ultrasonic waves have penetrating power that exceeds the NIR wave and the cost of investments is cheaper than X-ray waves. The purpose of this research was to study the characteristics of ultrasonic wave transmission to estimate the damage of purple sweet potato caused by the ‘lanas’ pest, non-destructively.

2. Materials and methods

2.1. Materials and tools
The material used in this study was purple sweet potato varieties of Ayamurasaki obtained from farmers in Ciampea Bogor with harvest age ± 3.5 months after planting. After harvest, sweet potatoes were cleaned (without using water) to omit the soil and dirt attached to the skin of the tubers. The purple sweet potato samples were selected manually as many as 105 tubers, which were 60 healthy purple and 45 purple tubers pest attack. This 45 pest attacked tubers were investigated visually and categorized from light to heavy attack according to [8]. A total of 2/3 parts of the sample was used in developing a model for estimating the damage of purple tubers as a result of pest attack, while 1/3 part was used as validation of the model that has been formulated.

The main equipment used for this research were ultrasonic wave measuring instrument that consisting of personal computer, digital oscilloscope, ultrasonic transmitter, transducer (transmitter and receiver) [9]. Frequency of transducer used was 50 kHz, 1:16 of sweep setting, time base of 400 μs/div, sample data for each measurement were 2048 data, with a sampling rate of 512 kHz. Other equipment used was a rheometer (Sun Rheometer type CR 300 DX-L) with a 5 mm diameter of cylinder probe to determine the hardness of purple sweet potato, the caliper for measuring the diameter of tubers, digital scales, and knife for destructive testing.

2.2. Measurement of Ultrasonic Wave characteristics and Physical Properties of Tubers
The measurement of ultrasonic wave acoustic properties was performed to obtain the data of wave velocity, coefficient of attenuation, and zero moment power, and done at the bottom, center, and end of tubers.

Measurement of hardness of tubers was done after the measurement of wave acoustic properties and carried out at the base, middle, and end of the tubers around the points of the measurement of the acoustic properties of the wave. Measurements were done using a rheometer that was set in the mode: 1, R/H (hold): 9.99 kg, P/T (press): 10 mm/m with a maximum pressure of 10 kg, and using 5 mm diameter cylinder probes.

Destructive testing and measurement were done to see the pest attack on tuber flesh, i.e., by peeling and cutting tuber flesh to observe the presence of lanas pest attack in the form of black spots, larvae pest larvae, and hole.

2.3. Data analysis

2.3.1. Ultrasonic Wave Velocity.
The ultrasonic wave velocity was determined by finding the transmission time, by measuring the difference of electrical pulses from the transmitting circuit and the receiver circuit [10]. The ultrasonic wave velocity was analyzed using digital oscilloscope output data calculated using equations 1.
$$V = \frac{s}{t}$$  \hspace{1cm} (1)

Where: 
\(V\) = velocity of ultrasonic waves (m/s) 
\(s\) = distance between transmitter and receiver (m) 
\(t\) = wave transmission time (s)

2.3.2. Coefficient of Attenuation.

The coefficient of attenuation shows the amount of energy loss in the ultrasonic wave after passing through the medium which is influenced by the type of medium passed. The cause of the loss of energy is the occurrence of absorption and other wave events such as reflection, refraction, diffraction, and scattering by the medium. The coefficient of attenuation is measured by observing the decrease of amplitude of the wave after passing through the medium and can be described as a function of the distance traveled by the wave [2].

The attenuation coefficient can be determined by converting the signal voltage sent and received after a certain distance [3]. According to [7], the magnitude of the attenuation coefficient is inversely proportional to the wave velocity. The more types of substances contained in the fruit, the more the interactions of the wave so that the coefficient value of attenuation is greater [10]. According to Mizrach et al. (1989) in [11], the magnitude of the ultrasonic wave attenuation can be calculated according to equation 2.

$$\alpha = \frac{1}{x} \ln \left( \frac{A_0}{A_x} \right)$$  \hspace{1cm} (2)

Where: 
\(A_0\) = Initial amplitude (volt) 
\(A_x\) = Amplitude after traveling x distance (volt) 
\(X\) = Distance travelled wave (m) 
\(\alpha\) = coefficient of attenuation (Np / m)

2.3.3. Zero Moment Power (Mo).

The value of zero moment power (Mo) serves to know the amount of energy transmitted on the material or medium that the wave transmitted. Mo is an area under power spectral density, which can be calculated by performing Fast Fourier Transform (FFT) using Matlab program in the form of amplitude and time relationships between power spectral density and frequency [12].

2.4. Model Development and Validation

The model development was arranged based on the relationship between ultrasonic wave characteristic and purple sweet potato condition. The model for estimating the damage of tubers as a result of the pest was determined by calculating the mean value between the average ultrasonic wave velocity, the coefficient of attenuation and the zero moment power on the healthy and the tubers attacked by the lanas. Based on the mean value, then it can be determined the limit of velocity, the coefficient of attenuation and Mo to differentiate between healthy and pest attacked of sweet potatoes.

The prediction of pest attacks based on a combination of ultrasonic wave characteristics was performed when the equation model constructed from each of the ultrasonic wave characteristic parameters has a good result to estimate the damage to tubers attacked by lanas pest. Model making was done by discriminant analysis to classify an individual or observation into a free and independent group based on a number of explanatory variables.

Validation aims to test the accuracy of the model equations that have been developed by calculating the success rate of tubers selection. Then for fitting the determining model were the success rate of sorting. The greater the success rate of the sorting, the more established the valid model. The rate of sorting errors was calculated using the confusion matrix or sorting error table by the apparent error rate (APER) method.
2.5. Discriminant Analysis

The basic model of discriminant analysis is denoted by the symbol of ‘d’, and the linear discriminant analysis model of the various independent variables is shown in equation 3.

\[ d = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + \ldots + b_nx_n \]  

(3)

Where: 
- \( d \) = discriminant score
- \( b \) = discriminant coefficient or weight (0, 1, 2, ., n)
- \( x \) = ultrasonic characteristics (1, 2, ., n)

The discriminant analysis procedure starts from the normal multivariate test for the significance test of the discriminant variable which is then followed by the equation-covariant variance matrix test. If the equation test of the variant-covariance matrix is not met then the quadratic discriminant function can be used. Evaluation of mean vector values between groups can be done by testing the hypothesis using multivariate variance analysis (MANOVA) with statistical tests that can be used such as Pillai’s Trace, Wilk’s Lambda, Hotelling’s Trace and Roy’s Largest Root.

3. Results and discussion

3.1. Damage of Tubers Due To Lanas Pest Attack

The grouping of the health and damage of purple sweet potato based on the physical characteristics of the tubers is still quite difficult to do accurately. The destructive test results on 45 damage samples and 60 healthy purple sweet potatoes are shown in table 1. Adult lanas pests attack the epidermis of the tubers and make a hole to lay its eggs. The eggs then hatch into larvae and create a hole in the tuber’s flesh before turning into pupa and imago (figure 1).

**Table 1** Results of manually sorting of purple sweet potato varieties of Ayamurarasaki

| Tuber Condition | Healthy tubers | Damage tubers |
|----------------|----------------|--------------|
| Black spot     | 0              | 45           |
| Hole           | 3              | 30           |
| Lanas larvae   | 0              | 16           |
| Healthy        | 57             | 0            |

![Figure 1](image)

(a) Healthy purple sweet potato and (b) purple sweet potatoes attacked by lanas

Hardness in the damaged purple sweet potato varieties of Ayamurarasaki by lanas pests was found higher than the healthy tubers. Hardness on purple sweet potatoes that was attacked by lanas about 29.96 kgf/cm² to 46.73 kgf/cm², whereas in healthy tubers was about 30.27 kgf/cm² to 42.31 kgf/cm², and statistically significantly different between them at the 5% test level, as can be seen in table 2.
Table 2. Average hardness of healthy and damaged purple sweet potatoes

| Characteristic | Healthy tubers | Damage tubers |
|----------------|----------------|---------------|
| Hardness (kgf/cm²) | 37.74 ±3.01 | 39.82 ±3.40 |

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

The purple sweet potato responds to the pest attack by producing toxic terpene compounds that cause tubers can not be consumed even at low concentrations and physical damage. The occurrence of malformation (abnormal growth of tissue or organs), thickening and cracks in sweet potatoes attacked by pests [13]. According [6], hole formed by the pest attack will dry and cause the decrease in the elasticity of the tuber tissue. Moreover, if the pest attack continues, the tuber will rot and the water content will increases.

3.2. Transmission Characteristics of Ultrasonic Waves

The ultrasonic wave acoustic properties used to predict damage to purple sweet potato due to pest attack are wave velocity, coefficient of attenuation and zero moment power. The nature of the wave is commonly used in the determination of the quality of agricultural products because it is influenced by the medium passed, and is not damaging medium passed.

Based on the measurement of the acoustic properties of the waves in the healthy and attacked by lanas pest sweet potato, it was found that the ultrasonic wave velocity value and Mo were lower in the healthy tubers than the tuber that attacked by lanas, while will have opposite effect for the coefficient of attenuation. Based on the result of analysis of variance with 95% confidence level, it is known that wave velocity, coefficient of attenuation, and Mo have p-value <α (0.05). It shows that there is a significant difference in the acoustic nature of the healthy purple sweet potato and pest attacked ones. The average value of ultrasonic wave characteristics in purple sweet potatoes is shown in table 3.

Table 3. Average value of ultrasonic wave transmission characteristics in purple sweet potatoes

| Characteristics | Healthy tubers | Damage tubers |
|----------------|----------------|---------------|
| Wave Velocity (m/s) | 235.30 ± 4.68 | 246.55 ± 5.50 |
| Attenuation (Np/m) | 42.41 ± 4.12 | 39.83 ± 4.70 |
| Mo | 18.20 ± 2.83 | 19.34 ± 2.80 |

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

The ultrasonic wave velocity is influenced by the internal condition and modulus elasticity of material. Based on statement of [14], [2], [9] and [10], the hardness of the material will be directly proportional to the wave velocity. The wave velocity of lanas attacked purple sweet potatoes was found higher than the healthy tubers. It is because the hardness of damage tubers is also higher due to the response of tubers that attacked by lanas would cause the thickening of the tissue. Also, ultrasonic wave velocity may also be influenced by water content. A study of ultrasonic evaluation for avocado maturity suggested that greater moisture content causing greater turgor pressure will result in greater ultrasonic wave velocity or positively correlated [15].

The greater attenuation coefficient in the healthy purple sweet potato is caused by its lower hardness compared to lanas attacked tubers. According [14], the amount of energy absorption that occurs depends on the physical characteristics of the wave. The process of wave absorption will often occur in solid medium, so that on raw pineapple fruit with low maturity and high hardness, attenuation coefficient value is smaller than pineapple fruit that has been mature. According to [4], coefficient of attenuation has negative correlation relationship (r = -0.81) with dragon fruit hardness, that is with increasing hardness tend to decrease the coefficient of attenuation.
Based on the coefficient attenuation equation by Mizrach (1989) in [11], the distance or diameter of the fruit is inversely proportional to the magnitude of coefficient of attenuation. The larger the diameter of the tuber that means longer ultrasonic wave transmission distance, the coefficient of attenuation will be smaller. The average diameter of healthy purple sweet potato was smaller than that of pests attacked ones, but not significantly different at the 5% test level. The average diameter of healthy sweet purple potato was 4.12 cm, whereas the lanas attacked tubers was 4.30 cm.

Zero moment power (Mo) shows the amount of signal energy transmitted on a medium. The greater the value of Mo in ultrasonic wave transmission then the transmitted energy the greater. The decrease in Mo value is directly proportional to the decrease in average wave magnitude [16]. Mo value obtained on healthy purple sweet potatoes is lower than that of pests attacked tuber. [2] mentioned that the value of Mo decreased along with the older durian fruit with increasingly declining its hardness. [11] also mentioned that the value of Mo tends to decrease with increasing maturity of bananas with a correlation coefficient R2 = 0.7431, the higher the Mo value then the fruit has a high hardness or still an-matured. The prediction of maturity of golden Apollo melons using audio sonic waves resulted in decreasing average Mo values with increasing age of harvest, i.e., from 142.67 ± 53.13 at harvest age 46 DAH to 51.52 ± 14.35 at harvest age of 67 DAH [16].

3.3. Prediction Model of the Damage Purple Sweet Potato Based on Wave Acoustic Characteristics

3.3.1. Wave Velocity.
The prediction model was developed using 2/3 of the total samples, i.e., 40 samples of healthy tubers and 30 samples of lanas attacked sweet potatoes. The ultrasonic wave velocity in lanas attacked purple sweet potatoes was found higher than the healthy purple sweet potato. The wave velocities of the tubers which was attacked by the lanas pest was arranged from 236.26 ms⁻¹ to 261.10 ms⁻¹, while in the healthy sweet purple ranges from 227.12 ms⁻¹ to 245.49 ms⁻¹ (figure 2).

![Figure 2. Ultrasonic wave velocity on healthy and lanas attacked sweet purple potato](image)

Based on the value of wave velocity of each group, it was obtained that the threshold value of wave velocity on healthy purple sweet potato and attacked by lanas is 241.24 ms⁻¹. The tuber that has wave velocity smaller than 241.24 ms⁻¹ were grouped into the category of healthy purple yam, while purple sweet potato with wave speed greater than 241.24 ms⁻¹ were grouped into the category of lanas pests attacked tubers. Mathematically, the limit of tubers damage due to pest attack by ultrasonic wave velocity is expressed in equations 4 and 5.

\[ V \geq 241.24 \rightarrow L \]  \hspace{1cm} (4)
Where $V$ is the ultrasonic wave velocity (ms$^{-1}$), $S$ is a healthy tuber and $L$ is the lanas attacked tubers.

3.3.2. Coefficient of Attenuation.

Sweet purple potato that was attacked by lanas pests was found having a lower average attenuation coefficient compared to healthy tubers. The coefficient of attenuation on healthy purple sweet potatoes ranged from 35.63 Np/m to 54.28 Np/m, whereas in the pests attacked tubers the coefficient of attenuation ranged from 32.18 Np/m to 50.75 Np/m (figure 3).

![Average coefficient of attenuation on healthy and pest attacked sweet potato](image)

**Figure 3.** Average coefficient of attenuation on healthy and pest attacked sweet potato

The threshold value of attenuation coefficient between the healthy and lanas pests attacked purple sweet potatoes was 41.38 Np/m. Sweet potato having attenuation coefficient greater than 41.38 Np/m belongs to the category of healthy sweet potato, and which has attenuation coefficient value less than 41.38 Np/m including in the category of sweet potato attacked by pests. Mathematically, the limits of damage of purple potato due to pest attack based on the coefficient of attenuation can be expressed in equation 6 and 7.

$$
\alpha \geq 41.38 \rightarrow S
$$

$$
\alpha < 41.38 \rightarrow L
$$

Where $\alpha$ is the coefficient of attenuation (Np/m), $S$ is the healthy tuber and $L$ is tuber attacked by sweet potato pest.

3.3.3. Zero Moment Power (Mo).

In addition to the wave velocity and coefficient of attenuation, the value of zero moment power (Mo) is also used to estimate the damage purple sweet potato due to lanas pest attack. Healthy sweet purple potato has a Mo value ranging from 13.73 to 24.00, while Mo in pest attacked tubers ranged from 13.91 to 24.68 (figure 4). Mo value in sweet purple potato was known from the measurement of ultrasonic wave characteristics in terms of amplitude and time relationship, i.e., by performing FFT.
Figure 4. Average Mo on healthy and pests attacked sweet potatoes

The threshold value used to determine the limit of damage between healthy and pests attacked purple sweet potato was 19.08. The tubers have Mo value greater than 19.08 belongs to the category of lanas attacked sweet potato, and that have Mo value less than the limit was a healthy purple sweet potato. Mathematically, the damage to purple sweet potatoes due to pest attack can be written as equation 8 and 9.

$$
Mo \geq 19.08 \rightarrow L \quad (8)
$$

$$
Mo < 19.08 \rightarrow S \quad (9)
$$

With Mo is the value of zero moment power, S is a healthy purple sweet potato and L is purple sweet potato that attacked by lanas pest.

3.4. Model Validation

3.4.1. Validation of Estimation Model Based on Ultrasonic Wave Velocity.
Based on equations 4 and 5, validation of the model to test the accuracy of the model equations has been established by calculating the success rate of tubers selection. The distribution graph of ultrasonic wave velocity validation data for model testing can be seen in figure 5.

Figure 5. Validation of damage estimation model based on wave velocity
Based on the data of ultrasonic wave velocity validation on healthy and lanas attacked purple sweet potato, there were 3 healthy sweet potatoes considered into the group of lanas attacked potatoes, and 2 attacked sweet potatoes classified into healthy sweet potato. An error in grouping of healthy and lanas pests attacked of purple sweet potato is presented in table 4.

**Table 4. Percentage of sorting errors based on wave velocity**

| From/to | Lanas | Healthy | Total | Error (%) |
|---------|-------|---------|-------|-----------|
| Healthy | 3     | 17      | 20    | 15.00     |
| Lanas   | 13    | 2       | 15    | 13.33     |

Based on equations 5 and 6, it was found that the prediction model of purple sweet potato damage due to pest attack can be categorized well with the percentage of success 85.71% and the value of APER of 14.29%.

3.4.2. **Validation of Estimation Model Based on Attenuation Coefficient.**

The model test using validation data of equations 6 and 7 can be seen in figure 6.

**Figure 6. Validation of attenuation coefficient of healthy and lanas attacked of sweet purple potato**

The result of the validation of the estimation model of tubers damage based on the coefficient of attenuation shows that as many as 9 healthy purple sweet potatoes are below the borderline or into the damage sweet potato group, and there were 4 damage tubers attacked by the pests that fall into the category of healthy tubers (table 5).

**Table 5. Percentage of sorting error based on the coefficient of attenuation**

| From/to | Sorting Results |
|---------|----------------|
|         | Lanas | Healthy | Total | Error (%) |
| Healthy | 9     | 11      | 20    | 45.00     |
| Lanas   | 11    | 4       | 15    | 26.67     |

The purple sweet potato’s grouping based on the attenuation coefficient has a fairly high error compared to the clustering based on the ultrasonic wave velocity. Successful in sorting of purple sweet potato was 62.86% with APER value of 37.14%.
3.4.3. Validation of Estimation Model Based on Zero Moment Power.
Based on equations 8 and 9 concerning the Mo value limit to estimate the damage of the purple sweet potato obtained the model validation results as in figure 7.

![Figure 7. Validation of the damage purple sweet potato estimation model using Mo](image)

The estimation of purple sweet potato damage due to pest attack using Mo value has an unfavorable success compared to grouping using wave velocity. In the estimation value of Mo 19.08, there was an error of grouping of healthy purple sweet potatoes by 25%, and tubers attacked by lanas pest was 40 %. The percentage of success of tubers sorting at Mo limit value was 68.57% with error (APER) of 31.43% (table 6).

**Table 6.** Percentage of miscellaneous purple potato error based on Mo

| From/to | Sorting Results | Healthy | Lanas |
|---------|-----------------|---------|-------|
| Healthy | Healthy tuber (n=20) | 5       | 15    | 20    | 25.00 |
|         | Lanas attacked tuber (n=15) | 9       | 6     | 15    | 40.00 |

3.5. Estimation Model of Lanas Attack Based on Combination of Ultrasonic Wave Characteristics
The grouping of purple sweet potato using a combination of ultrasonic wave characteristics was performed using discriminant analysis. Discriminant analysis is a method of knowing which variables differentiate a group from other groups within a population and can be used to clarify data based on differences in the characteristic data [17].

In determining a model, multi-collinearity testing is required to know that whether an independent variable in a model can be used in the formation of a discriminant function. The multicollinearity test results showed that the model did not experience multi-collinearity because the value of variance inflation factor (VIF) was less than 10 and the tolerance value was more than 0.1 (table 7), so the ultrasonic wave velocity, coefficient of attenuation and zero moment power had no linear relationship between variables and cannot be used as the predictor variable for the formation of discriminant function in estimating lanas pest attack on purple sweet potato.

**Table 7.** Multi-collinearity test among variable estimators

| Statistic | Wave Velocity (m/s) | Attenuation Coefficient (Np/m) | Mo   |
|-----------|---------------------|--------------------------------|------|
| Tolerance | 0.880               | 0.886                          | 0.99 |
| VIF       | 1.136               | 1.129                          | 1.00 |
In addition, discriminant analysis testing must satisfy several other assumptions, namely multivariate normal distributed data and have the same covariance matrix [18]. The normal multivariate test using the Chi-square plot (figure 8) was performed using SPSS version 15.0 with a significance value of 0.05. There is a high correlation between the distance of the mahalanobis with the Chi-square of 0.992, and the distribution of data tends to form a straight line with more than 50% (54.28%) of the value of the mahalanobis distance less than the value of the Chi-square. The significance value greater than 0.05 indicates that the data of the three variables are normally distributed.

The covariant matrix equation test was performed using Box's test of the XL-stat software to determine the homogeneity of the data used (table 8). The significance value> 0.05 indicates the covariant matrix between groups is homogeneous. The data condition used to predict pest attack on purple yam is multivariate and homogeneous normal distribution, so the discriminant function constructed is linear discriminant function.

![Figure 8. Quartile plot of Chi-square test of multivariate normality](image)

**Table 8. Result of equality test of covariance matrix**

| Test Results    | Value       |
|-----------------|-------------|
| -2Log(M)        | 9.481       |
| F (Observed value) | 1.502     |
| F (Critical value) | 2.099     |
| DF1             | 6           |
| DF2             | 27010       |
| p-value         | 0.173       |
| Alpha           | 0.05        |

An equivalent vector equation test was conducted to estimate the variables that could distinguish the healthy purple sweet potato group from attacked pests on the other site. Significance value (p-value) at wave velocity and coefficient of attenuation below 0.05, so it is considered to distinguish well between the healthy purple sweet potato and attacked by the lanas. While Mo has a significance value above 0.05, it means that singularly cannot classify well between healthy and damaged tubers.

After several assumptions or conditions in the preparation of discriminant analysis equations were sufficiently enough, the linear discriminant score function for the grouping between healthy and damage purple sweet potato were established which is shown in equation 10. The limiting value used is the cutting score of 0.3778. The purple sweet potato discriminant score greater than 0.3778 will fall into the category of damage tubers, while the lower ones will fall into the group of healthy tubers. Based on the
result of observation data analysis of both categories of purple sweet potatoes, then continued by made grouping based on proximity observation data to main values for each group.

\[
d = -51.273 + 0.213X1 - 0.008X2 + 0.041X3
\]  

(10)

Where:  
\( d \) = discriminant score for purple sweet potato  
\( X1 \) = ultrasonic wave velocity (m / s)  
\( X2 \) = coefficient of attenuation (Np / m)  
\( X3 \) = zero moment power (Mo)

Based on the validation done on the purple sweet potato grouping, there were 3 of 15 tubers attacked by pests into the category of healthy purple sweet potatoes, and 2 of the 20 healthy tubers fall into the category of lanas attacked purple sweet potato (table 9). It was found that the grouping done has a success rate of 85.71% with an APER value of 14.29%.

Table 9. Validation of purple sweet potato grouping using discriminant analysis based on a combination of ultrasonic wave characteristics

| From/to  | Lanas | Healthy | Total | Error (%) |
|----------|-------|---------|-------|-----------|
| Lanas    | 12    | 3       | 15    | 20.00     |
| Healthy  | 2     | 18      | 20    | 10.00     |
| Total    | 14    | 21      | 35    | 14.29     |

4. Conclusions and suggestions

An average ultrasonic wave velocity and the zero moment power (Mo) value were higher in purple sweet potato which attacked by lanas pests compare with healthy tubers, while an opposite effect was found for the average coefficient of attenuation. The result of discriminant analysis shows that the wave velocity, the coefficient of attenuation and Mo can be used to classify the healthy tubers and lanas pests attacked tubers, with the wave velocity as the dominant differentiator factor. It was found that success rate of the model was 85.71% with 14.29% of APER value.

References

[1] Nonci N 2005 Bioecology and control of the beetle Cylas formicarius Fabricus (Cleoptera: Curculionidae) Journal of Agricultural Research 24(2): 63-69.
[2] Haryanto B, Budiastra I Wand Purwadaria H 1999 Non-Destructive Quality Evaluation of Fruit with Ultrasonic Waves Agrimedia 5(1)
[3] Efriyanti N D 2006 Estimate the maturity level of sweet star fruit using ultrasonic waves (in Indonesian) (Bogor: Graduate School of Bogor Agricultural University)
[4] Djamila S 2010 Evaluation of dragon fruit quality non-destructively by ultrasonic method (in Indonesian) (Bogor: Graduate School of Bogor Agricultural University)
[5] Warji 2008 Estimation of arumanis mangoes damage caused by fruit flies using ultrasonic (in Indonesian) (Bogor: Graduate School of Bogor Agricultural University)
[6] Sutrisno A 2016 Detection of Cilembu sweet potato damage caused by lanas pest attack using ultrasonic wave (in Indonesian) (Bogor: Graduate School of Bogor Agricultural University)
[7] Nasution D 2006 Development of a non-destructive mangosteen fruits evaluation system with ultrasonic waves (in Indonesian) (Bogor: Graduate School of Bogor Agricultural University)
[8] Asmara V T 2014 Improved quality of purple sweet potato paste (Ipomea batatas L.) varieties of Ayamuurasaki through enzymatic hydrolysis process (in Indonesian) (Bogor: Graduate School of Bogor Agricultural University)
[9] Juansah J 2005 Design of ultrasound wave measurement system for grading of mangosteen (in Indonesian) (Bogor: Graduate School of Bogor Agricultural University)
[10] Sitompul Y D 2011 Characteristics of ultrasonic waves to detect the quality of Japanese cucumbers (in Indonesian) (Bogor: Graduate School of Bogor Agricultural University)
[11] Soeseno A 2007 Study of ultrasonic wave characteristics for banana maturity detection (in Indonesian) (Bogor: Graduate School of Bogor Agricultural University)
[12] Cheng Y and Haugh C G 1994 Detecting hollow heart in potatoes using ultrasound Trans. ASAE 37(1): 217-222.
[13] Ames T, Smit N E J M, Braun AR, O'Sullivan J N and Skoglund L G 1997 Sweetpotato: Major Pests, Diseases, and Nutritional Disorder (Lima (PE): International Potato Center (CIP))
[14] Luketsi W P 2016 Determination of maturity level of fresh pineapple fruit non-destructively by ultrasonic method (in Indonesian) (Bogor: Graduate School of Bogor Agricultural University)
[15] Self G K, Ordozgoiti E, Povey M J W and Wainwright H 1994 Ultrasonic evaluation of ripening avocado flesh Postharvest Biology and Technology 4 111-116.
[16] Agusta W 2016 Apollo Melon Fruit Maturity Detection Using Parameters of Sound Signal (in Indonesian) (Bogor: Graduate School of Bogor Agricultural University)
[17] Maria F, Dasari D and Heryanto N 2013 Discriminant analysis of student behavior in fast food (Case Study: Students at UPI, ITB, UNLA and UIN Sunan Gunung Djati) Journal of EurekaMatika 1(1): 107-116.
[18] Cheng Y and Haugh C G 1994 Detecting hollow heart in potatoes using ultrasound Trans. ASAE 37(1):217-222.