Central Mindanao University
Journal of Science
ISSN Print: 0116-7847 ISSN Online: 2704-3703

NON-DESTRUCTIVE ON-FIELD DETERMINATION OF PINEAPPLE (*Ananas comosus L.*) MATURITY USING ACOUSTIC IMPULSE IMPEDANCE TECHNIQUE

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ABSTRACT

This study was conducted to develop a model for non-destructive, on-field determination of pineapple maturity using acoustic impulse impedance technique. A total of 150 randomly sampled pineapple fruits from DOLE Philippines were used to evaluate the acoustic, physical and physiological properties of the fruit for calibration. The acoustic property (Hz) was determined using an improvised acoustic property tester and normalized the sound signal using a computer software. The physical properties evaluated were fruit height, weight, diameter, specific gravity and color. The physiological properties, i.e. sugar content, translucency, acidity, pith diameter and thickness of the rind were determined by cutting the pineapple fruits. Correlation and regression analyses revealed that there is a relatively good correlation between the sound frequency and number of days with R2 equal to 0.57. The regression model generated was then used to predict the maturity of the fruit using the frequency (Hz) during validation and it gave a RMSE equal to 3.2. Regression analysis between maturity and all non-destructive properties (i.e. acoustic and physical) was then performed and it showed a relatively strong relationship R2 equal to 0.72 (α = 0.01). Furthermore, model generated from regressing maturity and destructive maturity indices (i.e. translucency, sugar content, acidity, pith diameter and thickness of the rind) is highly significant (α = 0.01) in predicting pineapple maturity with adjusted R2 equal to 0.83. These findings could draw interest among researchers and pineapple farmers alike on the potential of using acoustic impulse impedance technique together with other non-destructive properties in determining pineapple maturity.

Keywords: Acoustic impulse impedance technique, pineapple maturity, non-destructive maturity determination

INTRODUCTION

Pineapple dominates the world trade of tropical fruits and is the eleventh most cultivated fruit with just over 24.8 million tons produced in 2013 (FAOSTAT 2015). With an increased consumer demand for fresh pineapple and juice amounting to nearly 30 billion pounds a year, the pineapple export industry has developed into a complex supply chain (FAO 2008). In the Philippines, an estimated area of 60,000 hectares is planted with pineapple, majority of which is situated in the provinces of northern and southern Mindanao. Nearly 70% of this total production is consumed as fresh fruits locally and the remaining 30% is intended for export. Of the total volume for export, only about 20% is fresh and the 80% is aimed at processing (UNCTAD, 2016). Importing roughly 65% of fresh pineapple shipment from the Philippines, Japan serves as the biggest export market for the Philippines followed by China, South Korea and Singapore (Balito, 2011).

With the increasing demand for fresh pineapple in the world market, Mindanao-based agribusiness companies were prompted to expand their capacities (Balito, 2011). Expansion came in the form of increasing production area, improving production technologies, and minimizing losses. There were continuous increases in area harvested of pineapple from Del Monte, Lapanday, Asian Hybrid, Mt. Kitanglad Agricultural Development Corporation, Davao Ventures Corporation and DOLE in Bukdinon in the 2nd half of 2011 (DA, 2013). Mechanizing pineapple production has also become widespread leading to improved production technologies. Unfortunately, one of the most crucial challenge in pineapple production is on minimizing the losses in the form of rejects against international quality standards of the importing countries. While rejected fresh pineapple are not at all losses since there is still high patronage within the local market, improved quality assurance procedure can greatly help in securing high production of fresh pineapple with export quality.

Presently, most pineapple producing companies employ visual and destructive method of determining maturity. Multinational pineapple companies employ external (visual) and internal (destructive) inspection of mature pineapple fruit on the field. Depending on the market on demand, a set of criteria like color and size, dictate the quality of marketable pineapple. Right colored, wrong sized, and conversely, will be sold to other markets

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Received: February 7th 2019; Accepted: April 8th 2021
DOI: https://doi.org/10.52751/fjvy1283

mostly at lower price. Right colored, right sized pineapples will undergo internal inspection. It will be cut and checked if the internal has the right color and translucency. This specific color is characterized by different maturity index like sugar content, acidity, soluble solids – acceptable to the market. For fresh pineapple export, not all the fruits are examined internally making it more vulnerable to standards. Any method, therefore, that employs non-destructive test for on-field quality inspection can optimize harvest productivity. This study aimed to evaluate the potential of acoustic impulse impedance technique in determining pineapple maturity.

METHODOLOGY

The research study was conducted in the machinery laboratory of the Department of Agricultural Engineering, College of Engineering, CMU, Musuan, Maramag, Bukidnon and samples were taken randomly from the pineapple plantation of DOLE Philippines, a nearby pineapple company in San Miguel, Maramag, Bukidnon.

A total of 150 fruit samples were collected and examined for this study. Sampling was done at 140 days to 160 days after pollination in 5-day increment, each with 30 fruit samples. The harvested pineapple fruits were transported on the same day to the laboratory where the fruit samples were subjected to different property tests. An improvised method of testing acoustic property was employed for the determination of the acoustic property of each fruit sample. The testing of acoustic property was done inside the laboratory room where isolation from unnecessary noise was secured. Then, a calibrated impact force was applied to 4 different locations around the fruit equator using an impact rod. The sound produced was recorded using ZOOM H1 Handy Recorder at a distance of not more than 10 cm from the fruit sample (Terdwongworakul, et al., 2009). The recorded sound frequencies were then normalized and digitized in a personal computer using the STEINBERG: WAVELAB LE software. This was done to determine the highest resonant frequency and to eliminate unwanted sound (noise) that was captured during the recording.

The physical properties taken from the fruit samples were the following: fruit height (H), which was determined by measuring the top to bottom part of the pineapple (without crown) using a Vernier caliper; fruit diameter (D), which was measured using a Vernier caliper through the horizontal diameter of the pineapple that is cut vertically; fruit weight (W), which was determined using a digital weighing scale; specific gravity (SG), which was taken as the fruit density to water density ratio; fruit color (C), which was determined using the DOLE Revised MG3 Fresh Pineapple Color Standard Guide.

To determine the physiological properties like translucency, sugar content, acidity, pith diameter and thickness of the rind, each fruit was cut and opened. Fruit translucency (T), which is a standard method for determining ripeness used in most pineapple plantations was determined using the float method where the fruit sample is submerged in water. Sinkers were identified as translucent while floaters are not. As to the degree of translucency, DOLE Premium Select Pineapple Translucency Chart was used as reference. Sugar Content (SC), measured in brix value (° Brix) – a specification parameter for pineapples – was obtained by conducting Brix test using a handheld refractometer. The acidity (A) of the fruit juice was determined using a digital pH meter. The pith diameter (PD) and thickness of rind (TR) were measured using a Vernier caliper.

Regression analysis was then performed to develop a mathematical model using the acoustic impulse as maturity index with characterization using the other properties. Additional 21 pineapple fruit samples were then used for validation. The predicting performance of the model was assessed by comparing measured or observed values and model predictions for the data in the independent validation set. The statistics for the performance assessment were R2 and standard error.

RESULTS AND DISCUSSION

Acoustic Properties of Mature Pineapple fruit

Figure 1 shows the acoustic property of the pineapple samples in Hertz (Hz) with respect to maturity

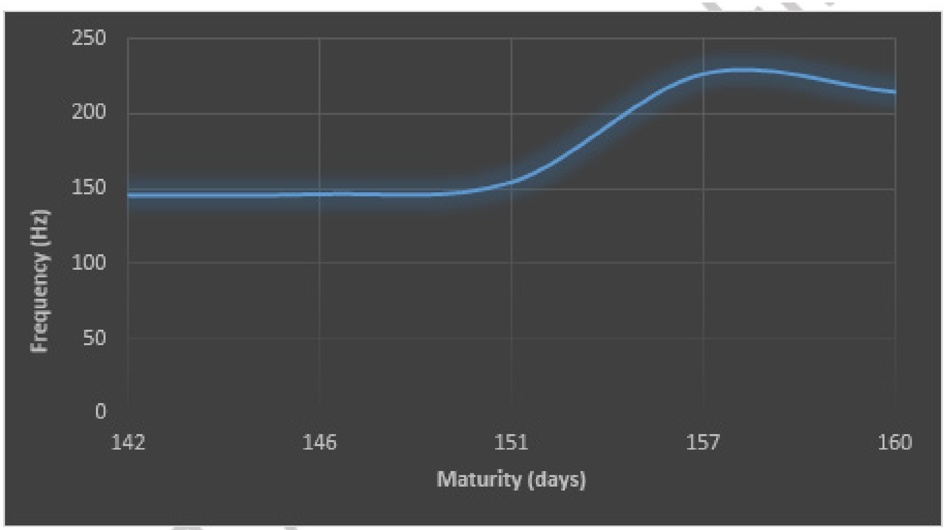

Figure 1. Recorded frequency with progressing days after pollination

Table 1

Physical properties of pineapple samples.

Days	Height (cm)	Diameter (cm)	Weight (kg)	Color
142	17.31	12.90	2.05	0
146	17.02	12.83	1.97	0
151	16.78	13.05	2.05	1
157	16.41	12.78	1.97	3
160	16.68	12.99	2.01	4

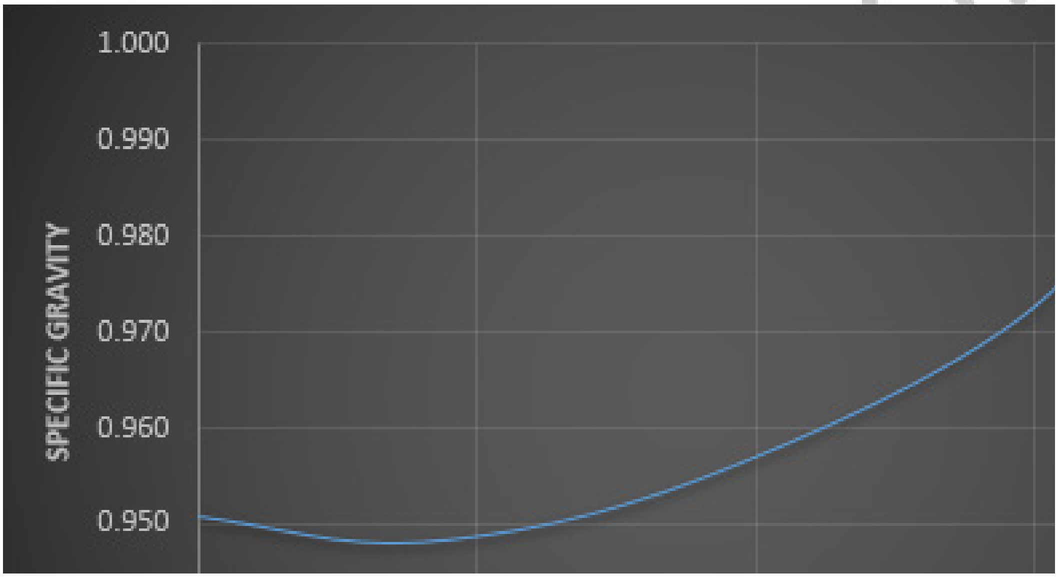

Figure 2. Graph showing the specific gravity of the pineapple fruit versus maturity

(days after pollination). The recorded frequency value ranges from 51 Hz to 305 HZ. At 142 days after pollination, the average frequency resulted to 144.605 Hz which increased significantly to 160.191 Hz at 146 days after pollination. The value continued to rise linearly until 157 days after pollination with a frequency of 237.82 Hz. A slight decrease was then observed at 160 days after pollination. This may be due to the fact that pineapple is non-climacteric, meaning that the pineapple does not exhibit any burst in respiration rate during its postharvest life. The pineapples collected on the 157th day were all considered as fully matured and since the pineapples collected were from the same area, any pineapple collected hereafter would mean that it is slightly overmatured, which could be the reason for that slight drop in resonant frequency. Another possible explanation for this is that at 142 days, pineapple is still on the final stage of its immature stage, therefore means that it is firm. The rind is harder compared to the ones at full maturity; hence, a lower resonant frequency. Generally, the sound frequency showed an increasing trend with progressing days after pollination.

Physical Characteristics of Mature Pineapple Fruit

Table 1 summarizes the recorded average values of the physical properties of the fruit samples specifically the fruit height without crown (cm), diameter (cm), weight (kg) and color which was based on the color chart given by Dole Philippines. The value of the weight ranges from 1.4 kg. to 2.5 kg. while its height ranges from 14.0 cm. to 20.72 cm. and the diameter ranges from 11.27cm to 14.51cm. At 142 and 142 days, majority of the fruit samples had color classified as 0 which is characterized by fruits with all eyes green and no color break. At 151 days, most fruits turned to shell color 1 which means the center of some eyes are beginning to show color break or one to seven eyes were observed with color break. The samples then shifted to shell color 3 at 157 days where majority (25% to 50%) of the eyes with color change. At 160 days, most of the fruit samples had majority of its eyes turned yellow (more than 50%), with some green color in between eyes which is classified as shell color 4.

Moreover, the value of specific gravity (Sg) of the fruit samples ranges from 0.91914 to 1.195 and it showed a generally increasing trend as the number of days progresses as shown in Figure 2.

Physiological Properties of Mature Pineapple Fruit

The physiological properties recorded include translucency (T), acidity (Ac) and sugar content (Sc) of the fruit juice and pith diameter (PD) and thickness of the fruit rind (TR). Table 2 presents the translucency grade of the fruit samples and its corresponding percentage in relation to the total number of fruit samples subjected to tests. The

Table 2

Translucency grade of the fruit samples and its corresponding percentage with respect to the total number of samples.

No. of Days	Translucency	Percentage (%)
142	1	100
146	1	80
151	2	46.49
157	3	74.17
160	3	83.33

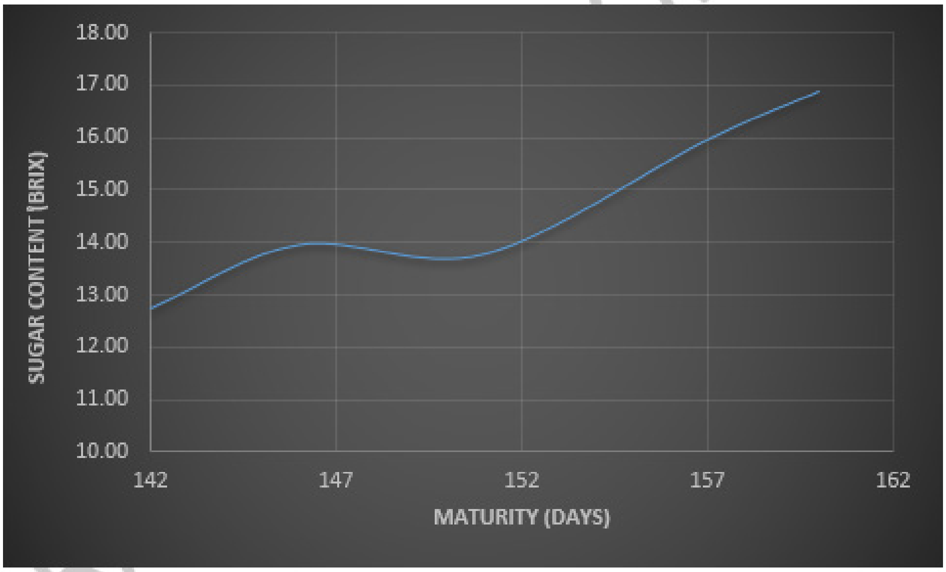

Figure 3. Graph showing the sugar content of the fruit with number of days after pollination

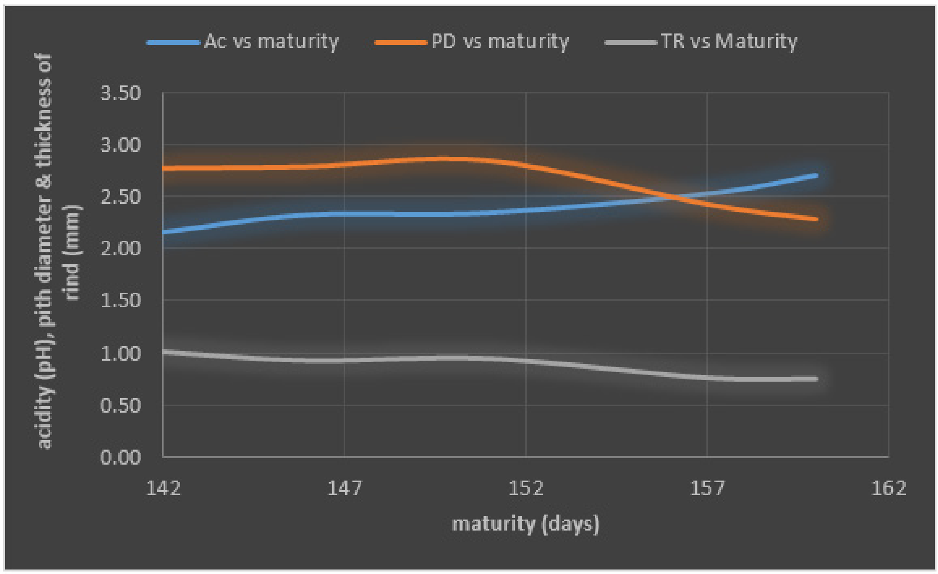

Figure 4. Graph showing the fruits' acidity, pith diameter and thickness of rind with respect to maturity

said rating was made using the translucency chart provided by the Dole Philippines. At 142 days, 100% of the fruit samples are graded 1 wherein the white flesh of the fruits is beginning to show traces of yellow color. The said rating remained as the majority grade (80%) of the fruit samples at 146 days. The rating rose to grade number 2 at 151 days comprising 46.49% of the total samples this means up to 50% of the fruits' flesh shows yellow color. Translucency grade number 3 was found to be the majority rating of the fruit samples at 157 and 160 days which consisted 74.17% and 83.33% of the total samples, respectively. This mark is characterized by fruit flesh that is 100% yellow with very light traces of darkened yellow watery tissue.

The sugar content (˚Brix), on the other hand,

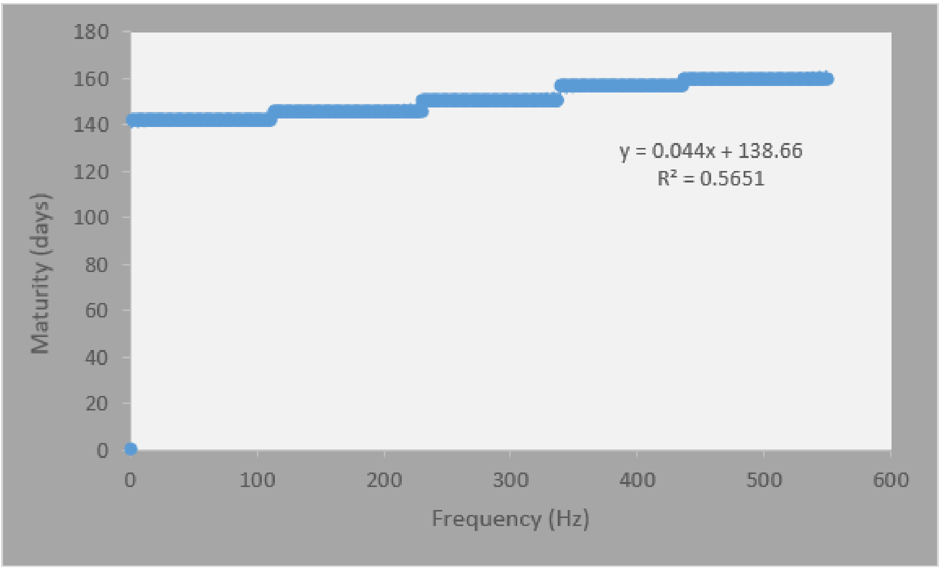

Figure 5. Graph showing the correlation of acoustic property vs. maturity.

Table 3

Regression model parameters for non-destructive maturity indices.

Source	Value	Standard error	t	Pr > |t|
Intercept	116.167	7.1600	16.2244	< 0.0001**
Frequency (Hz)	0.0164	0.0026	6.2262	< 0.0001**
Height w/o crown (cm)	-0.3770	0.2351	-1.6034	0.1094ns
Diameter (cm)	1.0205	0.5912	1.7260	0.0849ns
Weight with crown (kg)	0.6468	1.8139	0.3566	0.7215ns
Specific Gravity with crown	19.8307	3.3964	5.8388	< 0.0001**
Color	2.6482	0.0953	27.7991	< 0.0001**

* =significant
**=highly significant
ns= not significant

showed a generally increasing trend with increasing number of days after pollination as shown on Figure 3. Its value in ˚Brix ranges from 10.6 to 18.8.

Figure 4 shows the distribution of the acidity of the pineapple juice, pith diameter, thickness of the rind with time. The pH level of the fruits' juice showed an increasing movement as the number of days after pollination increases. At 142 days, the value was 2.15 and linearly increased to 2.324 at 146 days, then 2.343 at 151 days, 2.52 and 2.702 at 157 and 160 days respectively. Thickness of the rind on the other hand showed a decreasing trend with value 1.0113cm at 142 days, 0.928cm at 146 days and continued to decrease significantly at 151 days with a value of 0.75cm and then reached an average value of 0.747cm at 160 days. The pith diameter displayed an increasing movement from 142 days to 151 days but dropped significantly at 157 days until 160 days with values to equal 2.43cm. and 2.29cm., correspondingly. Pith diameter and thickness of the rind decreases with progressing days of maturity.

Correlation and Regression Analysis

Maturity versus Frequency

Figure 7 displays the correlation between the maturity (in number of days) and the acoustic property (Hz). The line shows a good relationship as validated by its coefficient of determination, R^2 which is equal to 0.57. This states that almost 60% of the variability of its maturity (days) is explained by the sound frequency (Hz).

The regression analysis between the number of days and acoustic property of the fruits (Hz) also revealed good relationship with R^2 equal to 0.22 and the model generated was *Maturity (days)*=0.05041×*frequency (Hz)*+141.97306. This equation was then used to predict the maturity of the pineapple to validate the model. A root mean square error equal to 5.93 during calibration and 3.20 during validation was eventually calculated based on the predicted and true value.

To further check the model significance, the results of analysis of variance for its regression analysis was evaluated and it showed that the probability corresponding to the F value is lower than 0.0001 which means there is lower than 0.01% risk in assuming that the null hypothesis (no effect of the explanatory variable) is wrong. Hence, the explanatory variable, Hz is significant. The residual plot also showed no identified pattern or trend which means the model is correct and there are no autocorrelations in the residuals.

Table 4

Regression model parameters for destructive maturity indices.

	Coefficients	Standard Error	t Stat	P-value
Intercept	122.533	2.3993	51.070	3.2E-216**
Translucency (Sliced)	3.1155	0.2072	15.033	2.43E-43**
Sugar Content/Total Soluble Solids (BRIX)	0.8912	0.0974	9.1452	1.01E-18**
Acidity	6.6534	0.7083	9.3939	1.33E-19**
Pith Diameter (cm)	-1.1848	0.3538	-3.3492	0.000863**
Thickness of Rind (cm)	-3.92719	0.9917	-3.9599	8.43E-05**

* =significant
**=highly significant
ns= not significant

Maturity versus non-destructive properties

To further check whether or not there is a possibility of predicting pineapple maturity using all non-destructive properties which includes acoustic and physical properties, a multiple linear regression analysis was performed using all these non-destructive properties versus fruit maturity. As shown on Table 3, the independent variables that are statistically significant in explaining the variation in fruit maturity are the frequency (Hz), specific gravity with crown and the color, as indicated by the calculated t statistics that exceed the critical values and the calculated p-values that are less than the significance level of 1%. Other independent variables do not add not significantly in explaining the variation in fruit maturity.

The results of regression analysis also revealed that the adjusted coefficient of determination, R^2, showed good relationship with value equal to 0.72 which means 72% of the variability of maturity (days) is explained by the frequency (Hz), specific gravity with crown and fruit color.

Maturity versus non-destructive properties

Table 4 presents the regression model parameters obtained from performing regression analysis of destructive maturity indices versus the days of maturity. As shown, the model generated indicates that all destructive maturity indices (i.e. translucency, sugar content, acidity, pith diameter and thickness of the rind) are highly significant (α = 00.01) in predicting pineapple maturity with adjusted R^2 equal to 0.83. This coincides with most of the pineapple company's conventional, destructive way of determining maturity by cutting the pineapple fruit and evaluating its physiological properties.

CONCLUSIONS

The sound frequency recorded from pineapple samples at different maturity showed a generally increasing trend but slightly dropped at 160 days which may be due to the fact that the pineapples collected on the 157th day were all considered as fully matured; since fruits collected were from the same area, any pineapple collected thereafter would mean that it is slightly over matured which could be the reason for that slight drop in resonant frequency. At 142 days, pineapple is still on the final stage of its immature stage; the flesh is more firm. The rind is harder compared to the ones at full maturity; hence, the resonant frequency is low. The weight, height and diameter of the fruits were not affected by its maturity since for that variety of pineapple, the company made sure that the fruits produced are of similar sizes for exportation purposes. On the other hand, the specific gravity increases as the days of maturity increases. The fruit becomes more dense and translucent. The sugar content and the acidity of its juice also rises as the fruit matures which is opposite to its pith diameter and thickness of the rind that both decreased with progressing days of maturity.

The correlation of the fruits' maturity and resonant frequency showed good relationship with R^2 equal to 0.57. Also, the model generated by regressing the acoustic property and maturity was able to predict the maturity of pineapple during validation stage with root mean square error equal to 3.20. A multiple linear regression analysis using all non-destructive properties versus fruit maturity was also performed and the model showed good relationship with value equal to 0.72 but has a greater value of RMSE (17.96) during validation compared to the first model. Moreover, the regression analysis of all destructive maturity indices (i.e. translucency, sugar content, acidity, pith diameter and thickness of the rind) versus maturity revealed that the conventional destructive methods is still the best indicator of maturity for pineapples with R2 equal to 0.83 at α = 0.01.

The acoustic impulse impedance technique is a widely used technique in various fields and is found to have potential on agricultural application. With the established method of employing the technique, any development for a tool, device or apparatus emanating from the potential of the said technique can reduce loses due to subjective fruit maturity identification; thus, enhancing pineapple production in the country.

RECOMMENDATIONS

Develop a more mechanized acoustic property tester that could better simulate the tapping force produced by a human finger. While this can be addressed by normalization, it would cancel any further bias attributed to human error. Use other softwares that can be purchased online, e.g. the spectrum analyzer pro, instead of Wavelab LE, which came free with the recording device. Lessen the collection interval from 5-day increments to 3-day increments starting from 130 days to 160 days and extend to over mature pineapples until 170 days. Extending data collention to 170 days could give insight on how the pineapple's explanatory variables behave at an over mature state. Determine mechanical properties to further characterize ripeness. This property was discarded during the study since the universal testing machine procured was not yet calibrated.

ACKNOWLEDGEMENT

The researchers would like to thank first and foremost, the Dole Philippines research team headed by Ms. Chona A. Hamlag for the pineapple samples used in this study and for taking the time to visit the university to assist in determining the physical properties of the fruits especially in assessing its color and translucency. Thanks also to the students who extended their hands during the conduct of this study and to the Agricultural Engineering Department of CMU for letting us use their laboratory for the tests and to the College of Human Ecology for lending us their refractometer. Most of all, boundless thanks to CMU through Research office headed by Ms. Angela Grace T. Bruno and her staff for the all the support rendered during the whole duration of the study.

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