Acoustic impulse response of young coconut (*Cocos nucifera* L.) fruits in relation to maturity

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Abstract: Acoustic impulse responses of young coconut fruits were analyzed using Fourier analysis and the correlation of signal characteristics with the mucous-like stage, cooked rice-like stage and leather-like stage maturity levels were determined. Analyses of sound signals of unshaved and shaved fruit samples were performed to determine if the difference in acoustic response could help enhance the differentiation of the fruits at different maturity levels. Results of statistical analysis showed that the frequency of the impulse response of the unshaved fruits increased with maturity levels and were significantly different from each other, while those of the shaved fruits were not. Also, results of regression analysis showed that as the fruits mature and the meat or kernel of the fruit thickened, sweetness of the juice also increased.

Keywords: young coconut fruit, acoustic impulse response, frequency analysis

Citation: Albalos, R. M. C., D. C. Suministrado, K. F. Yaptenco, and E. P. Quilloy. 2021. Acoustic impulse response of young coconut (Cocos nucifera L.) fruits in relation to maturity. Agricultural Engineering International: CIGR Journal, 23(1): 266-273.

1 Introduction

Cocos nucifera L., commonly known as coconut or coconut tree, belongs to the Arecaceae or palm family and is the only member of the *Cocos* genus. The coconut fruit is a drupe with a glossy and smooth exocarp, thick and fibrous mesocarp, hard endocarp, and a fleshy and edible endosperm. During younger stages, the endosperm inside the hollow center of the fruit is in liquid form which serves as a suspension for the embryo. As the fruit matures, the liquid endosperm coagulates onto the inner lining of the endocarp.

The immature or young coconut fruit, harvested six to eight months after flowering, are usually classified according to the state of the endosperm or kernel and are conventionally divided into three stages of maturity levels. In the Philippines, these maturity levels are called *malauhog* (M1) or mucous-like, *malakanin* (M2) or cooked rice-like, and *malakatad* (M3) or leather-like (Gatchalian et al., 1994). At M1 stage, the young coconut fruit is

Received date: 2020-01-06 **Accepted date:** 2020-04-18

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characterized by the thin, tender, and transparent meat which easily disintegrates and blends with the liquid component thus enhancing its flavor. The meat of the M2 fruit is opaque and thicker than that of the M1 fruit but can be easily scraped off from the shell without disintegrating with the juice and is palatable enough to be eaten raw. M3 fruits is hard and chewy and cannot be easily extracted from the shell. The meat is most appropriate for cooking candies and other delicacies.

There are no established specific indices that separate the three maturity levels of the young tender fruit. Although the terms *malauhog* or mucous-like, *malakanin* or cooked rice-like, and *malakatad* or leather-like indicate “hardness” levels, the classification is actually done by visual observation of the opened fruit, without the use of any instrument and without any standard basis.

The retailers and vendors of young coconut fruits (also referred to as *buko* in the Philippines) easily determine the maturity of the fruits by tapping the fruit with a *bolo*, a large machete shaped tool used for cutting, and judging the sound produced by it. This method is difficult to master and requires intensive practice and keen hearing. In order to verify the effectiveness of this technique and establish definitive maturity level differences of young coconut fruits, scientific analysis of the different properties of young coconuts with different maturity levels should be performed.

Sound is a vibration in the form of mechanical waves that travels through a medium such as air, water, and solid objects. There are numerous methods of visualizing and analyzing sounds, one of which is through Fourier analysis. The process involves transforming different physical phenomena into simple trigonometric functions for easier analysis (Folland, 1992). In the sound engineering field, Fourier analysis is used to decompose acoustic waves into sine and cosine wave components. Using this technique, the produced sound or the acoustic impulse response of young coconuts when tapped could be visualized and interpreted to gather useful results.

In this study, the acoustic impulse responses of young coconut fruits were analyzed using Fourier analysis and the correlation of signal characteristics with maturity levels was determined. Fruit samples were also shaved and the same analyses of the sound signals were performed to determine its effects on the acoustic response of the fruits. The intention was to determine if the change of the acoustic response could help enhance the differentiation of the fruits at different maturity levels. The maturity levels were also correlated with juice sweetness and meat or kernel thickness.

2 Materials and methods

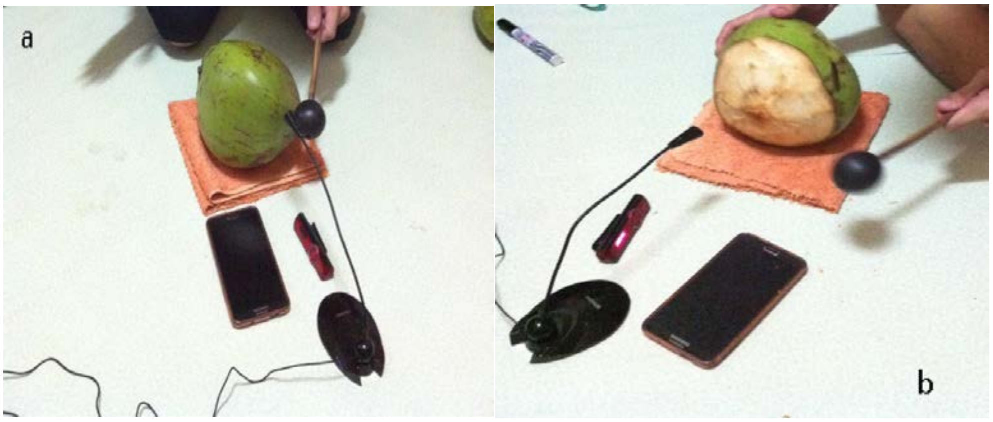
A total of 90 Laguna tall variety young coconuts, tested in batches within a three-week period, were used in this study. The fruit supplier was also requested to classify the fruits by maturity levels using the traditional tapping method. The results of his classification based on his skill would later be compared with the procedure using the Fourier analysis.

A rubber ball with wooden handle was used as the striker. The microphone used during the acoustic impulse response tests was the condenser type desktop computer microphone with sensitivity of -48 decibels (dB) ± 2 dB and frequency response of 20 Hz – 16 kHz. A digital refractometer was used to determine juice sweetness, and a Vernier caliper for meat thickness.

A laptop computer was used for data acquisition and analysis. Two computer programs and an online calculator were used. Audacity, an open source and multi-track audio recording and editing software was used for recording the acoustic impulse response of the young coconuts, normalizing and trimming the audio files, and transforming them to sound frequency data using the fast Fourier transform (FFT) algorithm (Audacity Team, 2016). For the statistical analyses such as one-way analysis of variance with post-hoc Tukey HSD (Honestly Significant Difference) test to be able to differentiate the acoustic responses of the three maturity levels, juice sweetness, and meat thickness, an online calculator in a statistical website (Vasavada, 2016) was used. For the tabulation of data as well as regression analysis, Microsoft Excel was used.

2.1 Data acquisition

All of the tests were conducted in a closed room with minimal echo and ambient noise. The acoustic impulse test was conducted by striking the samples using a striker near the fruits' tail (Figure 1a). The point of impact was 10 to 20 cm away from the microphone to properly record the produced sounds. After this, the bottom part of the samples was shaved or trimmed using a bolo until some of the endocarp were almost exposed. The fruits were subjected again to the acoustic impulse test with another set of strikes (Figure 1b). All of the recorded sounds in this procedure were saved to the computer for processing and analysis.



(a) Unshaved (b) shaved young coconut

Figure 1 Acoustic Impulse Tests

After the acoustic impulse response tests, the bottom part of the fruits was punctured to obtain fruit juice samples. The juice samples of each fruit were tested for sweetness three times using the digital refractometer. After testing the juice sweetness, the fruit samples were vertically split in half using the bolo to expose the endosperm and classify each fruit if it is in M1, M2 or M3 stage by visual inspection. Using the Vernier caliper, the meat thickness at the bottom part of the samples was measured. Three meat thickness measurements were obtained from different points near the tail of the fruits with visually differing thickness. Average of three values of sweetness and thickness measurements were used in the analyses.

2.2 Sound processing

The export settings of the recorded sounds include 320 kbps quality, fast variable speed, joint stereo channel mode, and mp3 file format. This setting is the highest quality possible for Audacity.

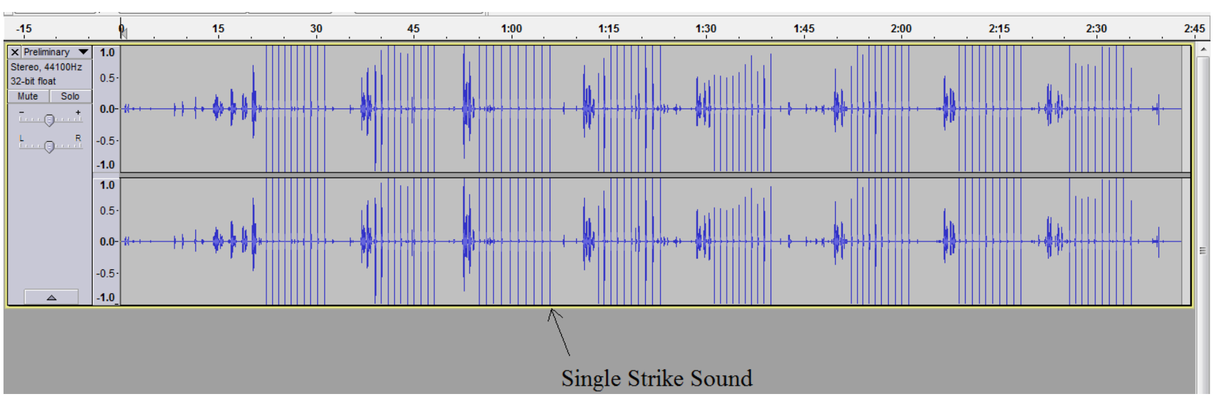


Figure 2 Example of an unedited recorded sound

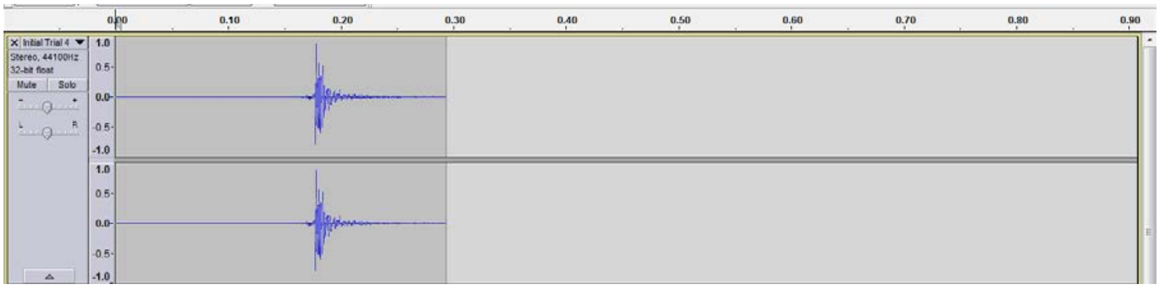


Figure 3 Example of an expanded single striking sound wave

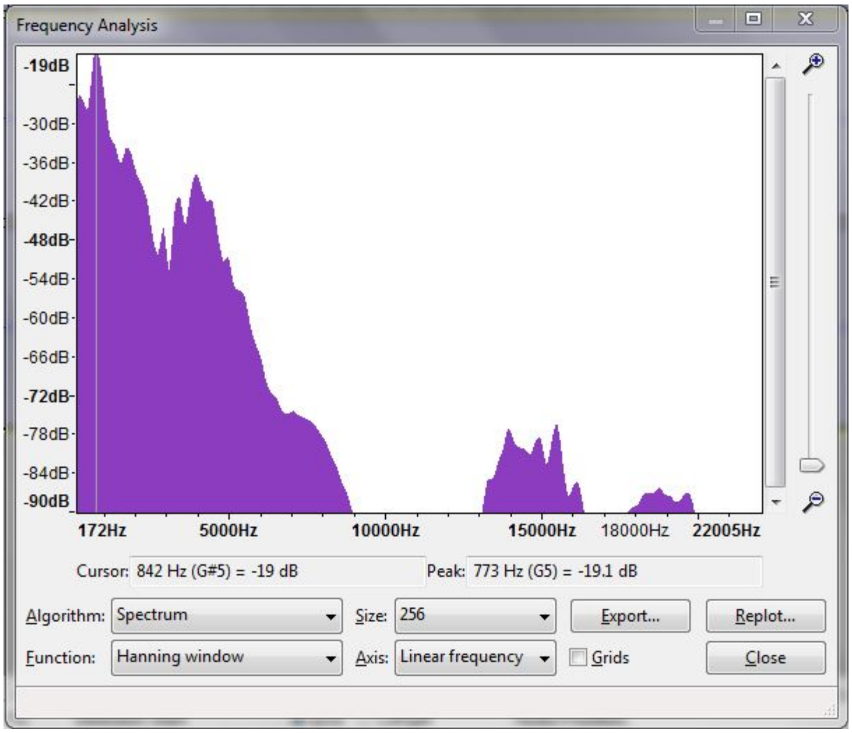


Figure 4 Audacity fast Fourier transform window

The unedited recorded set of strike sounds in stereo form (Figure 2) were all normalized to a maximum amplitude of -1.0 dB, the peak loudness for broadcast audibility, to eliminate the aspect of varying striking force which directly affects the intensity or loudness of the sound created during the tests.

After normalizing all of the recorded sounds, a single striking sound wave (Figure 3) was selected and trimmed to represent each young coconut sample. As these signals are in stereo form, only one (mono) was selected for analysis. The sound waves were all analyzed using the plot spectrum or fast Fourier transform of Audacity.

Figure 4 shows a fast Fourier transform window of Audacity with amplitude on the y-axis and frequency on the x-axis. The frequency with the highest amplitude of each sound signal data was obtained and recorded. (The sample figure shows a sound signal with its highest component frequency of 172 Hz.)

2.3 Statistical analysis

Microsoft Excel was used to tabulate all data. In order to determine if shaving of the husk of the young coconuts would affect the acoustic impulse response of the fruit, one-way ANOVA and Tukey HSD tests at 0.05 level of significance were performed on the values of the highest peak frequencies of the sound data of the unshaved and shaved fruits.

In classifying the young coconuts by maturity using acoustic impulse response, juice sweetness, and meat thickness, another series of one-way ANOVA and Tukey HSD tests at 0.05 level of significance was performed on the data. Regression analyses were also conducted to determine the correlation between sound data and juice sweetness, and between sound data and meat thickness.

3 Results and discussion

3.1 Unshaved and shaved fruits

The minimum and maximum values of the obtained frequencies with highest peak amplitudes from the 90 fruit samples in the unshaved and shaved conditions are shown in Table 1 with the calculated values of average and standard deviation.

Table 1 Peak frequencies of sound data of 90 young coconut samples in the unshaved and shaved conditions

Sample	Highest peak frequency (Hz)			
	Minimum	Maximum	Mean[1]	Standard deviation
Unshaved, *malauhog*, M1	327	573	451.07a	50.49
Unshaved, *malakanin*, M2	223	925	661.23b	184.00
Unshaved, *malakatad*, M3	490	1475	913.20c	217.69
Shaved, *malauhog*,M1	272	2383	611.83d	495.47
Shaved, *malakanin*, M2	276	1145	662.67d	191.16
Shaved, *malakatad*, M3	365	1291	795.73d	226.74

Note: [1]For each treatment, the mean peak frequency for each maturity represents the average peak frequency of 30 samples; for each treatment, means with a common letter are not significantly different by Tukey's HSD test at the 5% level of significance.

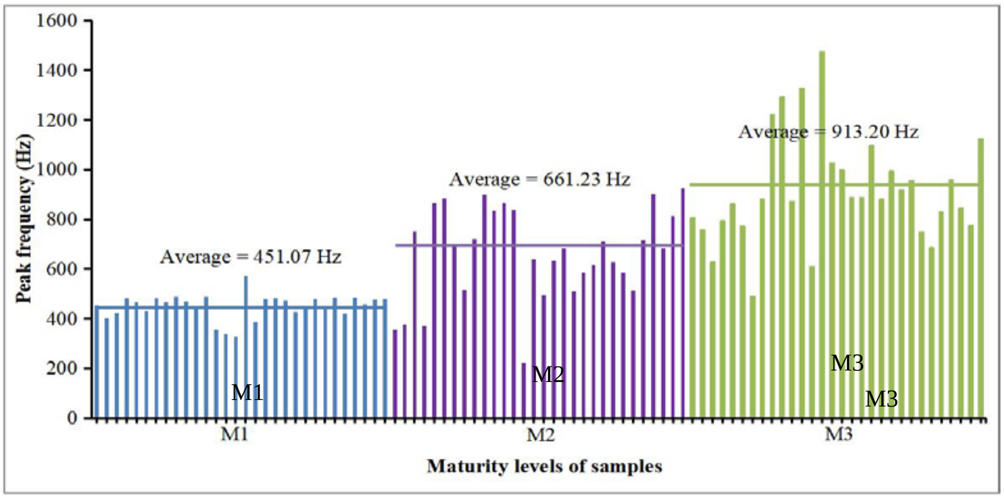


Figure 5 Highest peak frequency histogram of the unshaved young coconut samples

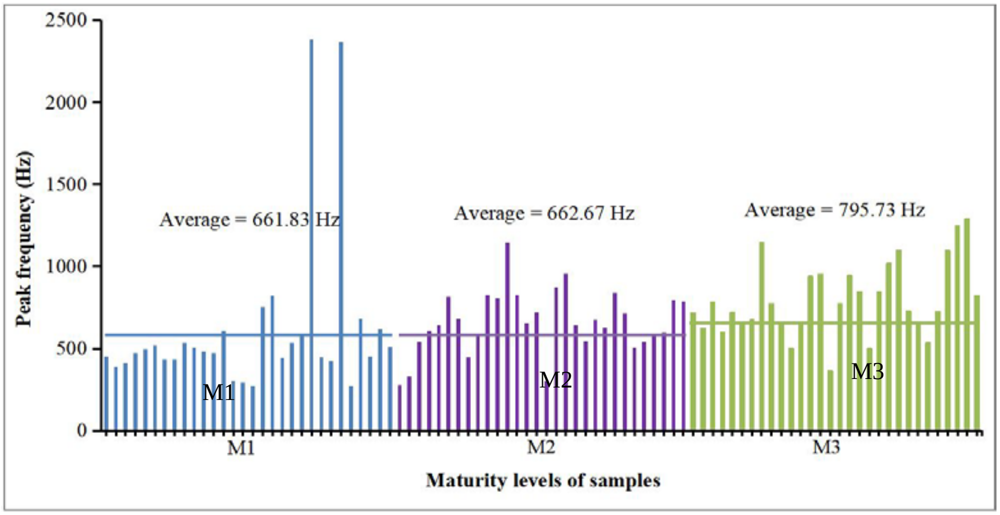


Figure 6 Highest peak frequency histogram of the shaved young coconut samples

Based on the values of the average highest peak frequencies of sound data obtained from each fruit, there is an increasing trend of frequency of the impulse response as the fruit matures. This confirms the same trend firstly reported by Gatchalian et al. (1994). The range of the frequencies, 200-1500 Hz, is much smaller than the range earlier reported by Suministrado (2006), i.e. 200-3,000 Hz, who also used Audacity for sound data processing and analysis. They are however higher than those of Suministrado (2007) who used Audacity for data trimming and DADiSP (Data Analysis and Display) for FFT analysis.

ANOVA and post-hoc Tukey HSD analyses of the data showed that the sound signals obtained from the unshaved fruit samples were statistically different among the three maturity levels while those from the shaved samples were not. This means that the unshaved condition of the fruit is more suitable than the shaved fruit for obtaining the sound indicator of maturity level using the highest peak frequencies of acoustic impulse responses. This agrees with the observation during the experiments where the loose and exposed mesocarp fibers of the shaved fruits seem to absorb some of the impact and acoustic impulse response caused by the striker compared to when the samples were unshaved and the complete force of the striker was completely reverberated towards and outwards the center of the fruit by the compact mesocarp. Plotting the highest peak frequency data of the unshaved (Figure 5) and shaved (Figure 6) samples on histograms visually confirms this observation where there is a clearer distinction between the plots of the unshaved than those of the shaved fruits.

As earlier mentioned, the supplier of the fruit samples was asked to determine the maturity of the fruits using the tapping method. He correctly identified the maturity of 81 out of the 90 samples. This gives him 90% accuracy in determining the maturity of young coconuts by judging the sounds that the fruits produced. This result gives merit to the capability and applicability of analyzing the properties of acoustic impulse responses in determining the maturity of young coconuts.

The tail area of the young coconut samples was chosen as the point of impact of the striker during the acoustic impulse test because this is the part of the fruit closest to the endocarp. It was originally theorized that sound data from shaved fruits would help improve the differentiation process. However, as data above showed, the shaving of the husks did not help to accentuate the magnitude of the frequency of acoustic response of the fruit.

3.2 Sweetness of juice and meat thickness

The data obtained on sweetness of the juice and meat thickness are summarized in Table 2 below. The table shows that the mature young coconuts have sweeter juices and thicker meats than the immature samples. The one-way ANOVA and the Tukey HSD tests further confirm that juice sweetness and meat thickness values are statistically distinct among the maturity levels ($p < 0.05$).

Table 2 Average and standard deviation juice sweetness and meat thickness of the young coconut samples

MATURITY	STATISTICAL SUMMARY[2]	JUICE SWEETNESS (% Brix)	MEAT THICKNESS (cm)
Malauhog, M1	Mean	5.58 a	0.35 a
	Standard Deviation	0.40	0.10
Malakanin, M2	Mean	5.93 b	0.55 b
	Standard Deviation	0.30	0.11
Malakatad, M3	Mean	6.25 c	0.92 c
	Standard Deviation	0.47	0.16

Note: [2]Average values of juice sweetness and meat thickness represent the mean of 30 samples. Means with common letter are not significantly different by Tukey's HSD test at the 5% level of significance.

Using the 90 sets of data, regression tests were conducted to determine how the acoustic impulse response of the unshaved fruits, juice sweetness, and meat thickness obtained from the young coconut samples are correlated.

As shown in Figure 7 and Figure 8, the correlation between the acoustic impulse response (and therefore, maturity) and juice sweetness is statistically significant ($p < .05$) although at a moderate level (Pearson's r = 0.453). The correlation between acoustic impulse response and meat thickness, is strong (Pearson's r = 0.747) as it is to be noted that the increase in thickness of the meat is an expected and natural phenomenon when the fruit matures.

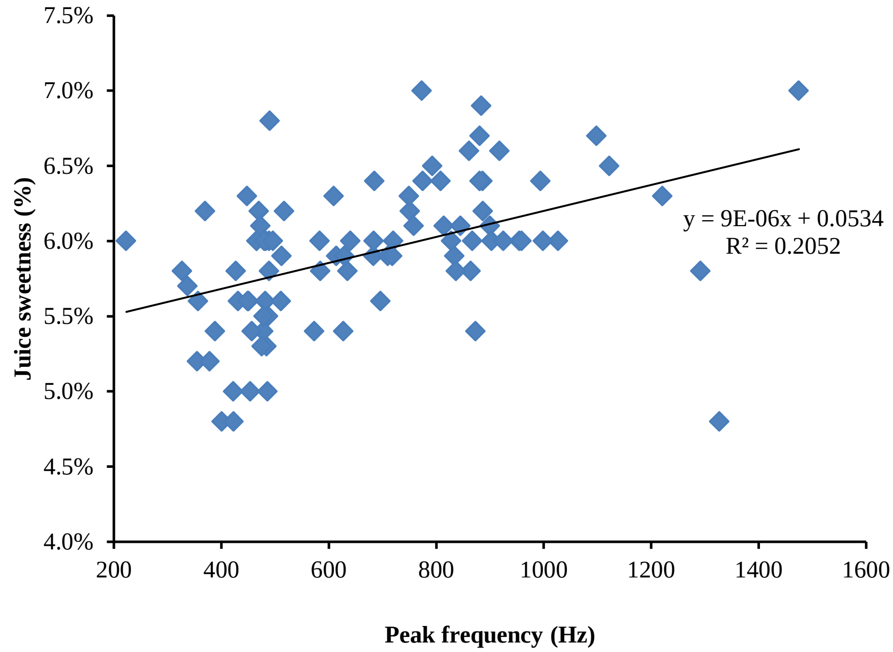


Figure 7 Correlation relationship between the acoustic impulse response, Hz, and juice sweetness, % Brix

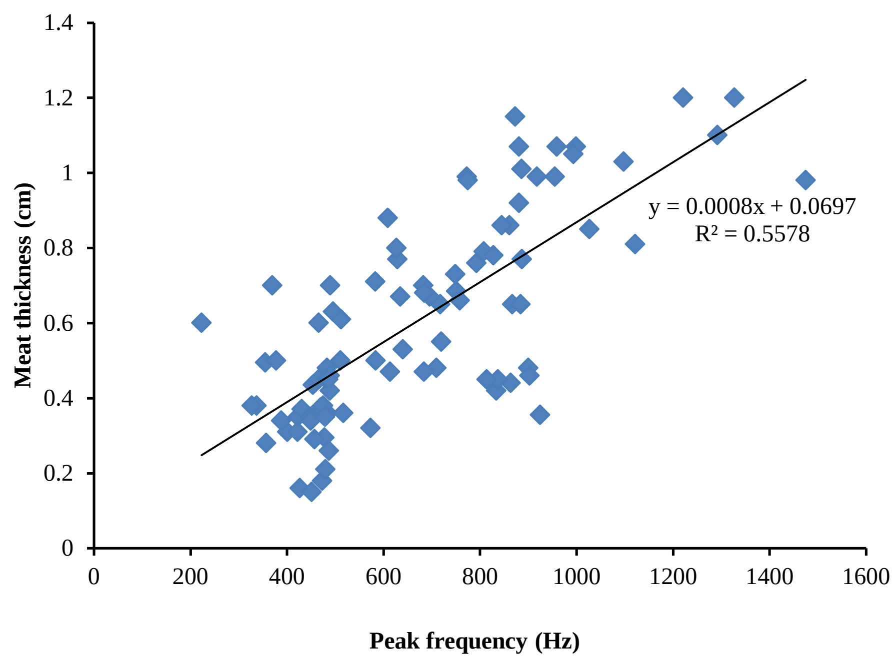


Figure 8 Correlation relationship between the acoustic impulse response, Hz, and meat thickness, cm

4 Summary and conclusion

In this study, the sound produced by striking 90

Laguna-variety young unshaved and shaved coconuts were obtained. Applying fast Fourier transform on the normalized recorded acoustic impulse responses enabled the extraction of the peak frequency data with the highest amplitude. These resulting data from the FFT of sound from the unshaved samples showed the potential for establishing the identity of the maturity levels of the fruits. Results showed that the sound signals from the unshaved samples were statistically distinct among the three maturity levels namely *malauhog* or mucous-like (M1), *malakanin* or cooked rice-like (M2), and *malakatad* or leather-like (M3).

Juice sweetness and meat thickness of each young coconut were also determined and were also found to be statistically distinct among the maturity levels. Regression analyses showed that there was moderate correlation between acoustic impulse response and juice sweetness and a strong correlation between acoustic impulse response and meat thickness.

Further development of this study may have to involve the development of an algorithm specific to the fruit or identification of the most appropriate software for sound signal analysis which can most effectively establish the distinguishing characteristics differences among maturity levels. Although Audacity, a free and open-source digital audio editor, was successfully implemented in this study, other software may be more effective for scientific applications such as this kind of research. The technique may also consider not only the peak frequencies of the sound data but also other sound patterns. Ultimately, the results of this work and of the others subsequent to this may be used to develop an application software or a portable mechatronic system for non-destructive testing of young coconut fruits as it duplicates the skills of vendors and retailers who can easily determine the maturity of young coconuts based on the sound produced by tapping the fruit.

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