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Non-destructive Measurement of Rock Melon Fruit Properties using Electrical Impedance Spectroscopy (EIS) Technique

M.S.A. Jumadi and D. Jamaludin*

[1]*Department of Biological and Agricultural Engineering, Faculty of Engineering, Universiti Putra Malaysia, 43400 Serdang, Selangor, Malaysia*

Electrical Impedance Spectroscopy (EIS) is a promising method that continuously develop in application of agriculture and food quality assessment. EIS sensor probe can be design to support non-destructive assessment which improve the conventional destructive method. Rockmelon is one of fruits with high demands in Malaysia thus the quality attribute such as moisture content, maturity, storage period and Brix Index are important to ensure high standard production. However, it is hard to assess these quality attributes on site because of current method and equipment are destructive and time-consuming. The objective of this study is to evaluate the feasibility of EIS to determine rock melon fruit postharvest quality parameters such as weight, moisture content and soluble solid content (SSC) using an impedance analyser board (AD5933) with a pair of electrocardiograms (ECG) electrodes at frequency range of 100 Hz to 100 kHz. The study shows that as the storage period is prolonged, the impedance value and moisture content of rockmelon are decreased while the weight-loss is increase but the SSC value shows inconstant pattern with storage period. The best frequency range of 400 Hz to 600 Hz was used to differentiate all samples based on their impedance value and storage period. The best prediction based on impedance value by linear regression model for storage period could be determined at frequency of 540 Hz with R^2 = 0.93 and the root mean square error (RMSE) = 2.48, while for moisture content is at 400 Hz frequency with R^2 = 0.81 and RMSE = 1.53. However, for SSC the impedance value could be determine using polynomial regression at frequency of 580Hz with R^2 = 0.63. From all these results, it indicates that electrical impedance properties have a good potential to develop a sensing system that can measure the rockmelon storage period, moisture content and weight without destructing the fruit.

Keywords: impedance; rock melon; moisture content; soluble solid content; storage period

I. INTRODUCTION

Every agricultural product has its own electrical characteristics which indicate the reaction of materials to the electrical field. It has been proved that any agricultural materials are capable of reflecting any changes through the electrical property's measurement. Liquids contained in any food will conduct electricity. Instead of electrons, charges that move across the liquid foods are in ions, which is dissimilar to metal. The mass of ions will carry charges as it passes through the electrical field in normal applications. This electrical conductivity will be regulated by the mobility and concentration of these ions (Zhang, 2007). Generally, the conductivity of a certain solution increases with the increasing hydrogen ions concentration at a given temperature (Clarkson, 1974). Thus, the concentration of hydrogen ions inside fruits varies accordingly.

Studies on electrical impedance spectroscopy (EIS) on agricultural produce properties have been conducted on several fruits and vegetables. The electrical impedance parameters of cucumber during cucumber drying procedure were studied and it was found that the magnitude of impedance decreased when moisture dropped from 95% to 68.05% after 210 minutes of drying (Liu *et al.*, 2007). Another study conducted on banana show that the impedance, phase angle, real and imaginary part of the

*Corresponding author's e-mail: diyana_upm@upm.edu.my

banana varies with the frequency as well as with the ripening state. The real part of the impedance increases with ripening and decreases with frequency. The composition change of the banana tissue may be correlated with the corresponding electrical impedance changes by conducting biological and biochemical analysis (Chowdhury *et al.*, 2015).

This paper describes the potential of EIS to determine rock melon properties such as storage period, moisture content and soluble solid content. Rock melon is getting popular among Malaysians because of its juicy and sweet tastes and also enriched with nutritional values such as protein, potassium, vitamin A and vitamin C that are good for the human body (Zulkarami *et al.*, 2010, Syahidah *et al.*, 2015). Rock melon is a climacteric crop where there will be rapid changes during the ripening stages. Therefore, many local markets are facing losses within short period which is between the post-harvest until the fruit is purchased by the consumers (Liu L., 2004). The sucrose content of rock melon fruit will not increase after harvest. Thus, this fruit will not be achieving optimum ripeness if harvested at unripe stage, while for the case of fruit that is overripe, the storage period will be affected. Therefore, it is crucial for growers and consumers to identify and categorized the postharvest properties of rock melon based on inner quality for better price.

Current method and equipment to measure these properties are destructive, costly and time-consuming. For instance, the method of determining the moisture content on weight basis using the oven drying method and soluble solid content using refractometer will cause the fruit samples to be no longer use for consumption and required hours to complete the test. Besides, it can only be performed with the laboratory equipment. Therefore, the development of new methods that correlated to this measurement to reduce the limitations is needed.

II. MATERIALS AND METHODS

A. Fruit selection and Preparation

The rock melon samples used in this study were selected based on variety and maturity stage. Thirty samples of "Glamour" variety were harvested at Permanent Food Production Park (TKPM), Department of Agriculture Serdang on 70 day after transplant (DAT) and stored inside a cold room for 27 days at temperature between 7 to 10°C with relative humidity of 85-90%. Measurement was done on day 1, 3, 6, 13, 20 and 27 days of storage. Non-destructive measurement such as fruit weight and impedance were executed first before proceeding to the destructive measurement on fruit moisture content and soluble solid content.

B. Fruit Weight Measurement

Rock melon fruit weight was measured using a weighing balance to determine weight loss throughout the storage period.

C. Electrical Impedance Measurement

AD5933 analyser board (Analog Devices Inc., USA) was used to measure the impedance and phase data in the frequency range of 100 Hz to 100 kHz (Figure 1). To ensure the measurement were taken without destructing the fruits structure, a pair of electrocardiograms (ECG) electrodes was placed in parallel position on the rock melon surface and connected with crocodile clips to the AD5933 board. A 200kΩ resistor must be connected to the Vin and Vout of the AD5933 board. Start frequency, frequency interval, number of increments, clock system and calibration impedance were registered in the user interface AD5933 Evaluation Software. Results from the measurement such as impedance and phase data were downloaded in Excel file form.

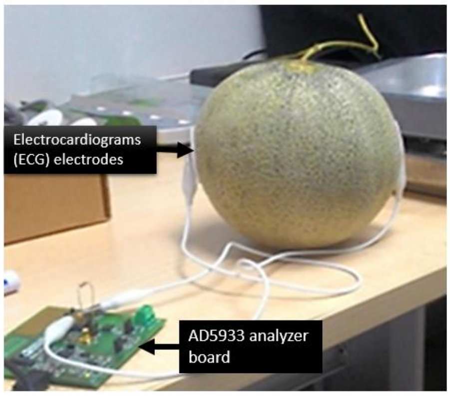

Figure 1. Electrical Impedance Spectroscopy using ECG probe on rockmelon skin to determine its properties

D. *Moisture Content Measurement*

Samples with dimension of 1 cm x 1 cm x 1 cm were prepared for each fruit. Then, each of these samples was placed into the dish and the weight of the dish with the cubic sample was recorded before placing into the oven for drying. Samples were dried at 105°C for 24 hours. Then, the dish with the dried sample was placed onto the desiccator to cool and the weight after drying for each one (dish + sample) was recorded. The weight of the dish is deducted as both initial weight and weight after drying were including weight of the dish. The moisture content of the samples was calculated based on the formula below:

$$\textbf{Moisture (\%)} = \frac{W1-W2}{W1} \times 100\%$$

where

$W1$ = Weight (g) of the sample before drying, and

$W2$ = Weight (g) of the sample after drying.

E. *Soluble Solid Content (SSC) Measurement*

The rock melon fruit that was cut into half is used for impedance measurement and the other half will be used to extract the juice for the measurement of SSC. Sampling for juice is quite simple but still need to ensure that the right extraction was made to obtain a good result. At first, the skin was peeled off using a knife and the seeds were scrapped out gently with spoon. Then, the slice of the rock melon flesh was cut into three parts to make an average measurement of the SSC on the different part of the flesh which also can represent the location of flesh with the highest reading. Next, each part of the flesh samples was blended using a kitchen grinder until it becomes juice.

The easiest way in measuring the SSC is by using a device called refractometer with Brix value. This device uses the principles of light refraction where light rays that passing through a liquid will bends. The denser or thicker liquids will refract more. In this procedure, the SSC of the rock melon is measured using a digital Pocket Refractometer PAL- α (AtagoCo. Ltd) which can measure Brix level in range of 0 to 53 %Brix as shown in Figure 2.

Figure 2. Pocket Refractrometer to measure Brix level of rockmelon

These procedures are based on the guides provided by Organisation for Economic Co-operation and Development (OECD). For each juice samples that was prepared, an equal number of drops (5 drops) was placed onto the refractometer prism plate by using the syringe. Then, the "Start" button on the refractometer was pushed to get the SSC level in % Brix. After used, the prism was cleaned with dry tissue and recalibrate by using the distilled water before proceeding with another measurement of other samples. Distilled water will give a zero reading, and if not, it needs to be adjusted the get the zero reading. Average reading from three parts of the rockmelon flesh was made from the results which represent the SSC level of the whole fruit.

III. RESULTS AND DISCUSSION

A. *Relationship Between Storage Period and Quality*

The quality of rock melon is measured based on its weight, soluble solid content and moisture content. The regression, correlation and one-way ANOVA was undertaken to find the significant changes and relationship between all parameters for different groups. The analysis was done on 6 groups of different storage period with 5 samples in each group.

1. Changes of Weight Loss during Storage

Weight of fruits has become one of the common parameters used in determining the fruit ripeness and represents the moisture content in the fruits. Results show that there is reduction in rock melon weight from day 1 to day 27 of the experiment. The correlation between storage period and weight loss was found to have significant differences ($p \leq 0.05$). There is a positive relationship between weight loss and storage period which shows that the weight loss was increased as the storage time increased (Figure 3). Fresh harvested fruits tend to decrease in weight due to reduction in water status. Fruits with a loss of 5% - 10% from its initial weight are considered as unmarketable (El-Ramady *et al.*, 2015). From this experiment, it is found that the fruits with storage period between 20 and 27 days after harvest have an average weight loss about 5% and 7% respectively. This concludes that rock melon fruits which are stored more than 15 days will experienced more weight loss and cause low market value.

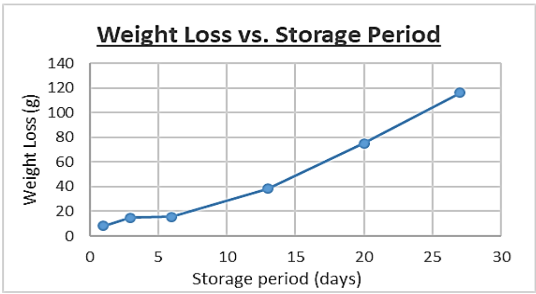

Figure 3. Weight loss changes during storage period

2. Changes of Moisture Content during Storage

The correlation analysis between storage period and moisture content was found to have negative relationship and is statistically significant ($p \leq 0.05$). From the Figure 4 below, it shows that the moisture content decreased as the storing period increase. According to Holcroft, D. (2015), the harvested fruits will start losing water by transpiration as the plant part for water supply is removed and cause weight reduction.

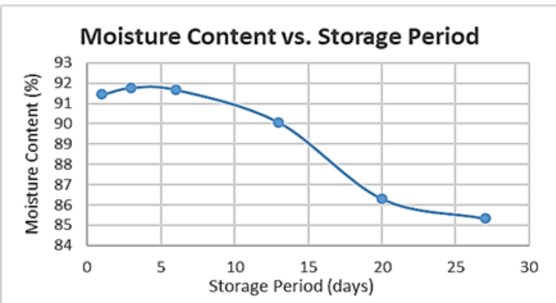

Figure 4. Moisture content changes during storage period

In regression analysis, the R^2 value is 0.87, which means that storage period accounts for 87% in variation of moisture content of the fruits. Thus, this conclude that storage period is one of major factor on moisture content reduction in rock melon fruits. In one-way ANOVA analysis, there is significant differences between each storage period. The Tukey Post Hoc test shows that there is significant difference in moisture content for day 6 storage with 13, 20 and 27 days of storage. However, between day 1 and day 3 of storage time, there is no significant differences in moisture content. Thus, this conclude that the moisture content is significantly reduced starting at day 6 of storage and above.

3. Changes of Soluble Solid Content during Storage

The changes of SSC within storage period is shown in Figure 5 below. The graph shows that the SSC starts to decrease during day 1 to day 5, but after day 5 the SSC hikes up from 11%Brix to 12.6% Brix in day 13. After day 13, the SSC start to decrease again. This pattern shows that the effect by storage time to the SSC level is not constant. The reasons of having this pattern of graph is might be due to several factors that influence the SSC levels for each sample. In previous researched by El Assi *et al.* (2010), the variation in SSC value for rock melon only significantly correlated with day after sowing or planting where delaying harvesting time will result in higher SSC levels. Rock melon was classified as fruits that capable of continuing their ripening process once removed from the plant but not increasing in SSC level (Kader, 1999).

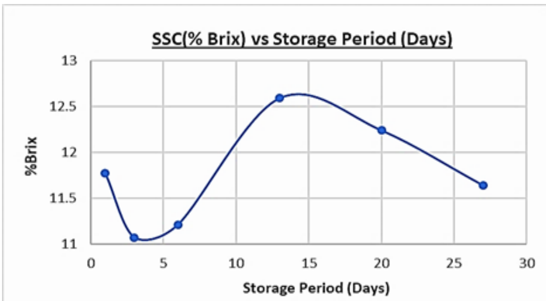

Figure 5. Soluble solid content changes during storage period

B. *Relationship between Electrical Impedance and Fruit Maturity*

1. Impedance vs. Frequency for different storage period

The electrical impedance spectroscopy was run at full frequency range for all samples between 100 Hz to 100 kHz.

The low range frequency (400Hz to 600 Hz) shows significant differences among all samples compared to the high frequency range (Figure 6). This also shows that impedance value decreases as frequency increase. From this graph, it shows that the impedance value decreased each day from day 1 to day 27 of storage period at frequency of 470 Hz.

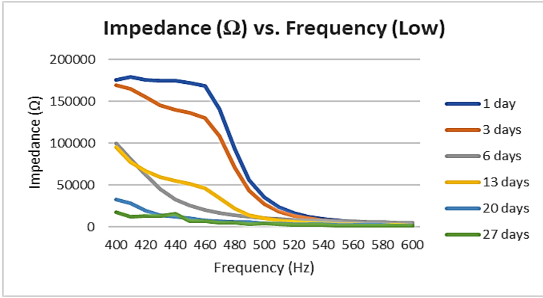

Figure 6. Impedance (Ω) against frequency (Hz) from 400 Hz to 600 Hz for different storage period

Table 1. Regression analysis on impedance and maturity ages at significant (P≤0.05) frequencies

Frequency (Hz)	Regression Equation	R^2	RMSE
400	y = -1.478E-4 (x) + 26.23	0.91	2.93
410	y = -1.388E-4 (x) + 24.25	0.86	3.51
420	y = -1.330E-4 (x) + 22.96	0.79	4.32
430	y = -1.263E-4 (x) + 21.18	0.72	5.00
490	y = -3.880E-4 (x) + 20.45	0.68	5.25
500	y = -5.717E-4 (x) + 22.06	0.72	4.45
510	y = -0.001 (x) + 23.876	0.78	4.45
520	y = -0.002 (x) + 26.181	0.85	4.82
530	y = -0.002 (x) + 28.243	0.91	3.99
540	**y = -0.003 (x) + 30.057**	**0.93**	**2.48**
550	y = -0.004 (x) + 31.176	0.92	2.49
560	y = -0.005 (x) + 31.549	0.87	3.68
570	y = -0.005 (x) + 31.249	0.80	4.10
580	y = -0.005 (x) + 30.063	0.71	5.08
590	y = -0.005 (x) + 28.311	0.63	5.77
600	y = -0.005 (x) + 26.674	0.56	6.25

A regression equation for a prediction of rock melon storage period based on its impedance value was made for each frequency. A good regression model was found on the frequency of 540 Hz (Figure 7) which have the highest R squared value and the lowest root mean square error (RMSE). The R square value shows that this model has the independent variables that accounts for 93% in variation of dependent variable while the RMSE is 2.48.

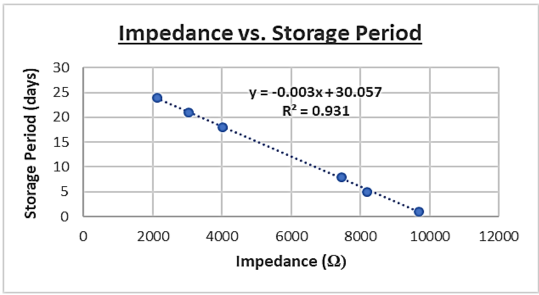

Figure 7. Impedance versus Storage Period from 400Hz to 600Hz

C. *Relationship between Impedance and Moisture Content*

The correlation analysis between impedance and moisture was conducted for frequency range of 400 Hz to 600 Hz. It was found that there were nine frequencies had positive relationship with the moisture content (p≤0.05). The best linear regression model for moisture content prediction based on impedance value was selected from these nine frequencies.

From the analysis it was found that frequency of 400 Hz shows the highest R square value (0.81) with the lowest root mean square error (RMSE). This conclude that this frequency has the best linear regression model for moisture content prediction where the higher the impedance value of rock melon fruit, the higher the moisture content.

Table 2. Regression analysis on impedance and moisture content at significant (P≤0.05) frequencies

Frequency (Hz)	Regression Equation	R^2	RMSE
400	**y = 3.931E-5 (x) + 85.564**	**0.81**	**1.15**
410	y = 3.567E-5 (x) + 86.204	0.72	1.41
520	y = 4.203E-4 (x) + 85.810	0.67	4.45
530	y = 0.001 (x) + 85.215	0.75	3.32
540	y = 0.001 (x) + 84.662	0.79	1.63
550	y = 0.001 (x) + 84.277	0.81	1.19
560	y = 0.001 (x) + 84.085	0.79	1.67
570	y = 0.001 (x) + 84.086	0.75	2.13
580	y = 0.001 (x) + 84.316	0.70	2.36

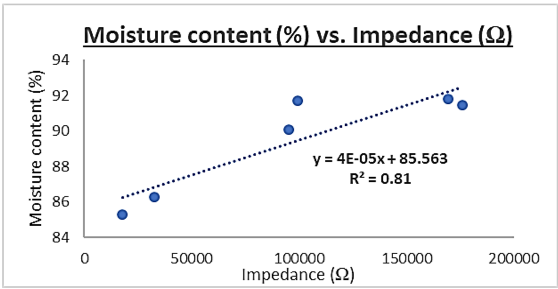

Figure 8. Moisture content (%) versus impedance (Ω) at 400 Hz frequency

D. *Relationship Between Impedance and Soluble Solid Content*

The soluble solid content shows polynomial pattern at 3rd order with R^2 =0.63 at 580Hz. This is the highest coefficient determination of impedance with SSC. However, from the graph patterns it explained that the effects by impedance measurement is not constant.

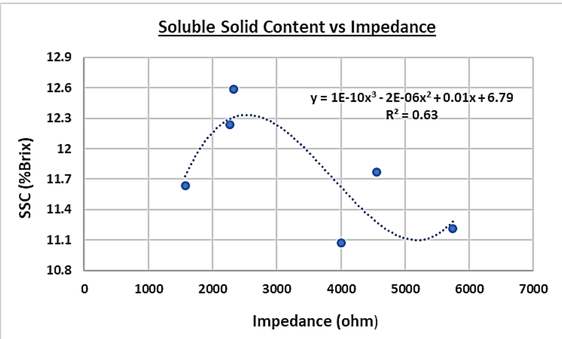

Figure 9. Soluble solid content (%Brix) vs. impedance (Ω) at 580 Hz

E. *Other Findings: Chilling Injury*

There is one sample at day 27 of storage which experienced chilling injury. In previous research by German et. al. (n.d.), storing at low temperature is an effective postharvest method for extending the shell life of the fresh produce but chilling injury is the common problem that may occurred at certain period of time. This may cause the fruit to loss in firmness and also have some bruises, and at the same time reduces the quality of the fruit. In this case, the rock melon fruit is suggested to be stored not more than 20 days for temperature of 8°C to ensure the eating quality is maintained. Referring to Figure 2, the water loss is as much as 7% after day 20 which considered as undesirable quality for consumption.

IV. CONCLUSION

From the results of this research, there is indication that electrical impedance spectroscopy (EIS) can be a useful method for rock melon quality assessment such as moisture content, storage period and soluble solid content. This method has a good potential to develop a sensing system that can measure the rock melon quality without destructing the fruit. The uses and advantages of EIS should be further explored for agricultural applications in future. However, there were some improvement that can be implemented for future applications based on this research. The following future works are recommended:

1. The electrical impedance measurement could incorporate with other parameters such as firmness, colour, and texture.
2. The electrodes for non-destructive measurement should be improving to reduce or replace the limitations by ECG electrode.

V. ACKNOWLEDGEMENT

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