Study of Soluble Solid Content in Limau Madu with Capacitive Sensing Technique

Hudaliyana Ghazali, Rafidah Rosman and Zaiton Sharif

***Abstract*— *Limau Madu* is one of two types of citrus that are widely planted in Malaysia. Prior to being marketed to the end users, the *Limau Madu* would go through the grading process. Among the criteria for a good grading is the taste. However, testing the taste of *Limau Madu* non-destructively is often challenging. One of the methods to determine the solid soluble content of *Limau Madu* non-destructively is capacitance sensing technique. The capacitance is measured at different frequencies for several days. The finding shows that as the longer orange is being kept, the permittivity of the fruit, ε_r declines. In term of frequency, permittivity of *Limau Madu* is highest at frequency of 10 MHz. However, it is different case with SSC which slightly increased over the course of seven days. The performance of the fruit has better impact at lower frequency.**

Keywords—capacitance; soluble solid content; limau madu

I. Introduction

In Malaysia, the production of citrus fruits is mainly for the domestic market; they are grown in commercial orchards, backyard orchards and smallholdings in various parts of the country [1]. One of the famously planted citrus in Malaysia is *Limau Madu* which is widely planted in the states of Pahang, Kedah, Perak, Terengganu, Johor and Sarawak. The fruits are cheaper than imported oranges and have high vitamin C content [2]. Before it is commercially marketed, the citrus fruit including *Limau Madu* need to be graded into certain categories which can influence the price of the fruit. The fruits can be graded manually or by a grading machine. Grading is done according to their size, weight, shape and less damaged resulting from pest infestation [3, 4].

According to the Malaysian Standard specification, grading of citrus fruit is based on the size and quality of a fruit [3]. Quality of a fruit is depending on the percentage of damage. The lowest grade is grade A because it has 25% of damages and the diameter is only around 50 to 59 mm. The best fruit is graded as AAA because its diameter is more than 70mm and damage is equal or less than 5% [3].

In this study, the capacitance of *Limau Madu* grade AAA is observed at different frequencies to determine the solid soluble content (SSC) of *Limau Madu*. SSC is regarded as sugar in respect to density and other quality control measurements[5–9]. The study intend to propose that while previous method of grading is useful and commercially used, the determination of fruit solid soluble content also can be regarded as one of the features for grading the fruit.

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II. Basic Principle

Capacitance sensing method gained a lot attention from researchers around the world due to its simplicity and low cost. From small material such as grain and nuts to the bigger material such as papaya and watermelon, are being used as experimental object. There was a study on categorizing fruits based on density by measuring the hollowness and estimate SSC of the whole watermelon non-destructively using low cost electronic instrument. The soluble solids content of watermelons can be estimated from density and mass through relationships established by multiple regression analysis. It became clear that there was an optimum range of density that could be used as an indicator of watermelon quality. Watermelon with a density of 0.94 to 0.97 g / cm 3 were relatively high in sugar content and without cavities [10].

Apart from density sorting, moisture content and ripening stage have been discussed via capacitive sensing. C.V. Kandala and J. Sundaram measured moisture content of grain, nuts and different type of wheats. The idea of developing a low-cost system which compromise of impedance meter and a parallel-plate capacitance to measure moisture content is done with grains, nut and also for different types of wheat. The reason behind this is the conventional impedance meters have extra features that are not significant in their studies and is expensive [6–9] . The capacitance of low-cost system which is made-up of parallel-plate is given by;

$$C = \varepsilon_r \varepsilon_o A/d \qquad (1)$$

Where A is area of plate, d is plate separation, ε_r is dielectric constant of the material between the plate and ε_o is the permittivity of free space (8.854×10^{-12} F/m) [12].

III. Material and Methods

In this study, the experiment is divided into three sub-section. The first section would be on collecting the samples and their preparation. The second part of the experiment is measuring the capacitance of *Limau Madu* non-destructively. This is done to obtain capacitance value without damaging the fruit. The final stage of this experiment is destructive method. This is done to obtain the oranges internal attribute in numerical form.

A. Sample

A number of *Limau Madu* of the same grade is collected at the same place which is at a nearby orchard. They are tagged and kept at lab temperature which is 26°C. Their weight are recorded every day.

B. Non-destructive method

The experiment is conducted with *Limau Madu* sandwiched between two parallel aluminum plates. A source of 5V is connected to the circuit and a capacitor with a value of 10pF is used to give stability in the circuit. V_{out} is measured using a multimeter. The readings of V_{out} are recorded at frequencies of 10 MHz, 15 MHz, 20 MHz and 25 MHz. Figure 1 shows the experimental set-up. This set-up is prepared by adapting the procedure used in several studies conducted by Soltani et al. [14].

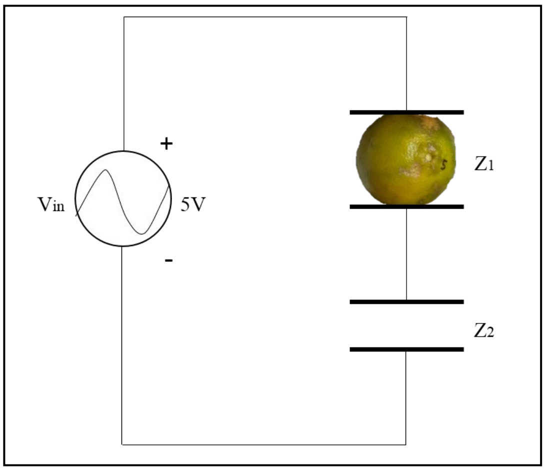

Fig. 1. Experimental set-up [8]

C. Destructive method

This method is done to yield more information on the brix, acidity, pH and moisture content of the samples. All of the oranges were cut into half and pressed for their juice. The juice is filtered to avoid any excess of pulp and seed.

- *pH measurement* Taking measurements of pH is completed by using a Combo pH/EC/TDS/Temperature with Only One Tester (Model HI 98129 . HI 98130). Prior to pH measurements, the instrument is first calibrated using pH 4.01 Buffer Solution (±0.01 pH at 25°C). Then, pH mode is selected with the SET/HOLD button. Electrode is submerged into the solution to be tested.
- *Brix and Acidity measurement* Brix and acidity are measured using digital hand-held pocket refractometer (Hybrid PAL-BX|ACID F5 ATAGO). To measure brix only 0.2 ml of orange juice is needed and the solution is dropped on the prism surface of the pocket refractometer. The solution is then diluted with about1.0 ml deionized water to obtain the acidity.
- *Moisture content measurement* The flesh and seeds of orange are placed back into their skins and stacked in an aluminium tray. The tray of oranges is retained at 75°C for 24 hours in a dry oven. After 24 hours, the dried oranges are weighted.

IV. RESULTS AND DISCUSSION

A. Result from non-destructive method

Figure 2 shows relative permittivity of *Limau Madu* for seven days. During this period, ε_r slightly increased from day one to day 3 and decreases from day three to day seven for all frequencies. It is highlighted that ε_r at 10MHz has the highest value.

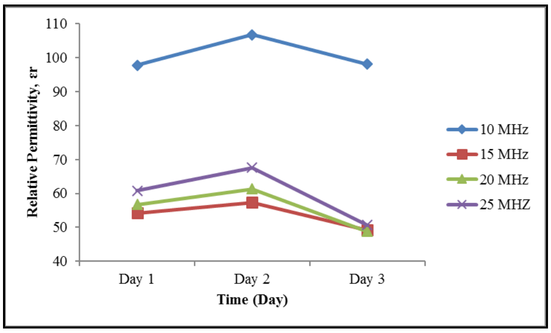

Fig. 2 Relative permittivity, over days of *limau madu* at different frequencies

On the other hand, figure 3 provides overview for the capacitance of limau madu for that course of seven days. As stated in equation (1). Thus, as ε_r increases, C will also increase.

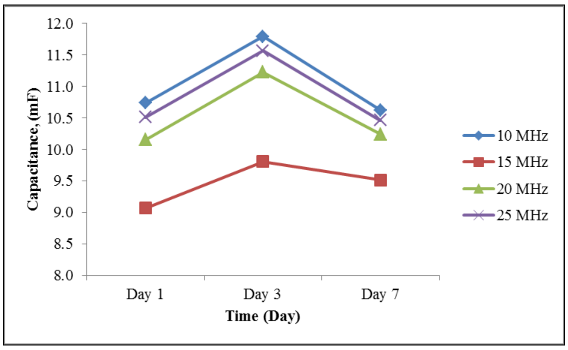

Fig. 3. Soluble solid content of limau madu during the duration of seven days

Therefore, it is expected that destructive results are better at lower frequency.

B. Result from destructive method

TABLE I. R^2 VALUE OF CAPACITANCE AT EACH FREQUENCY

	Capacitance at Each Frequency			
	10MHz	*15MHz*	*20MHz*	*25MHz*
Brix	0.8718	0.4594	0.0357	0.2019
Moisture content	0.6580	0.4429	0.9288	0.2546

	Capacitance at Each Frequency			
	10MHz	***15MHz***	***20MHz***	***25MHz***
Acidity	0.7229	0.1545	0.2788	0.2184
pH	0.7620	0.7254	0.8451	0.4700

The coefficient of determination, R^2 of every variable at each frequency are presented in Table 2. Ideally R^2 is the proportion of the total variation in each variable studied experimental response accounted for by the regression model[15]. The value of R^2 always lies between 0 and +1. Mathematical definition of R^2 is given by:

$$R^2 = 1 - \left(\frac{RSS}{TSS}\right) \quad (1)$$

In equation 1, RSS is residual sum of squares while TSS is total sum of squares. Theoretically, the R^2 is resultant from equation 1. By plotting the data that have been obtained in MATLAB, the value of R^2 is numerical computed [16]. Hence, it is significant in this study. The value of R^2 can also determine the linearity of the relationship of two variables studied. A value close to 1 indicates a strong positive linear relationship [15].

As can be seen from the table, as the frequency increases, R^2 are set out to decline. Except at frequency of 20 MHz, the R^2 for moisture content and pH are high. Overall, data at 10 MHz are considered promising as R^2 for each variable are more than 0.5. These results of linear regression proved a better estimation for the parameters involved which are brix, moisture content, acidity and pH. This result is somewhat counterintuitive. The linear function of every variables at frequency 10 MHz are summarized into table 3.

TABLE II. MULTIPLE LINEAR REGRESSION EQUATIONS AT 10 MHZ

	Function	R^2	***Frequency***
Brix	= 0.7062x + 2.2562	0.8718	10 MHz
Moisture content	= 0.3219x – 16.101	0.6580	10 MHz
Acidity	= -1.1847x + 12.122	0.7299	10 MHz
pH	= 4.8741x – 8.301	0.7620	10 MHz

This regression equation which is also considered as theoretical regression value offers prediction of the dependent variable. The resolution of the multiple linear regressions is to use the independent variable with known values to predict the dependent variable. The value of R^2 validate the equations, hence the value closer to 1 gives better prediction [17].

These functions represent the regression between capacitance and brix, moisture content, acidity and pH. Closer inspection of the table shows that R^2 for brix is higher than other variables. Brix is much closer to capacitive property. Positive linear functions are shown in figure 4, 5 and 6. A negative linear function between capacitance and acidity is shown in figure 7. This prove good linear correlation exists between capacitance and all variables.

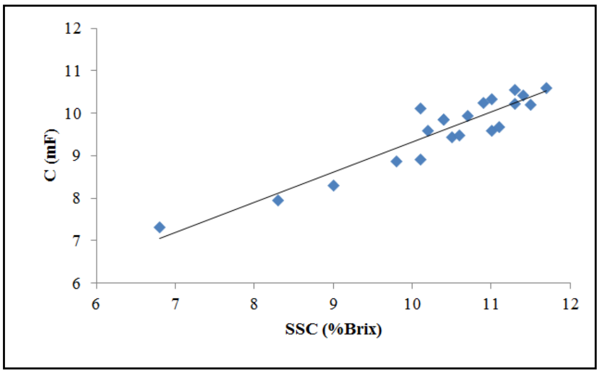

Figure 4. SSC and Capacitance of *limau madu* at 10MHz

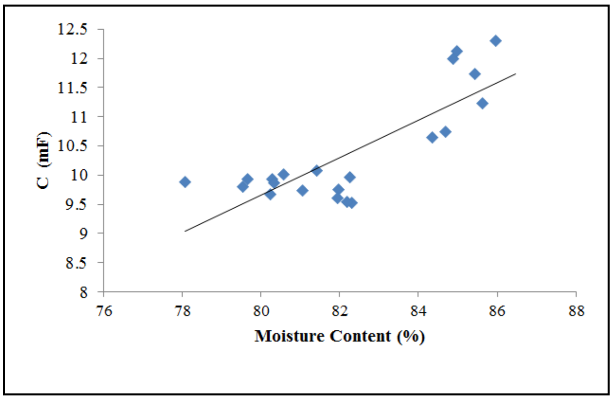

Figure 5. Moisture content and Capacitance of *limau madu* at 10MHz

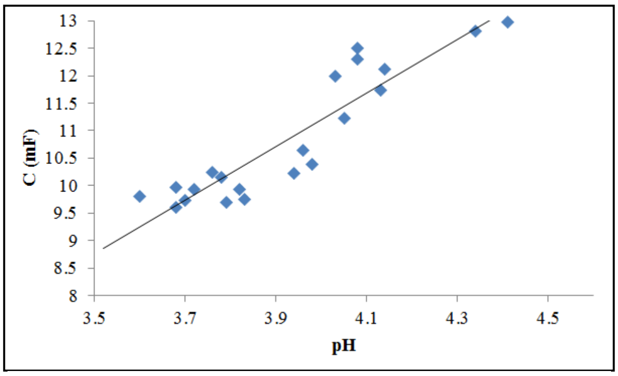

Figure 6. pH and Capacitance of *limau madu* at 10 MHz

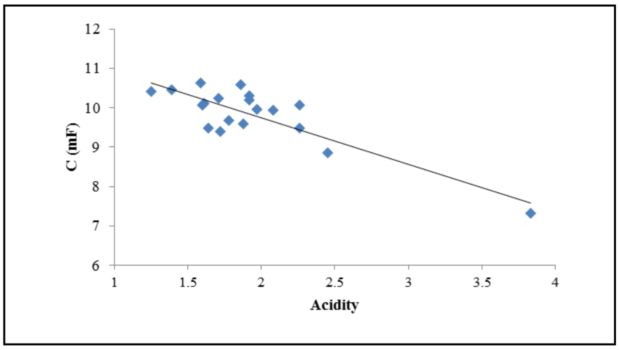

Figure 7. Acidity and Capacitance of *limau madu* at 10MHz

It is typical for oranges fruit to have a pH range from 3.6 to 4.5. At these pH range values the fruits are considered acidic [18]. As pH increases, acidic decreases simultaneously.

V. CONCLUSION

It can be concluded that properties of *Limau Madu* can be correlate to its capacitance at different frequencies. In this study, frequency of 10 MHz has shown a strong R^2 and prove strong relationship between capacitance and soluble solid content (SSC) of *Limau Madu*. The reading of SSC can determine the sweetness of *Limau Madu* non-destructively, which can categorize the fruit according to different grade. The study can provide a value added for current grading system by considering the sweetness of fruit as part of the feature for grading the fruit. Nonetheless, this study is bound with limitations. In order to observe the capacitance and frequency closely, variations range frequency should be applied.

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References

[1] H. Shokrollah, T. L. Abdullah, K. Sijam, S. N. A. Abdullah, and N. Psyquay Abdullah, "Differential Reaction of Citrus Species in Malaysia to Huanglongbing (HLB) Disease using Grafting Method," *Am. J. Agric. Biol. Sci.*, vol. 4, no. 1, pp. 32–38, 2009.

[2] B. M. Allen, *Malayan Fruits. An Introduction to the Cultivated Species*. Singapore: Donald Moore Press, Ltd, 1967.

[3] C. L. Shen, A. R. Ghani, R. Suhood, N. Jumat, and H. Arbaen., *Pakej Teknologi Limau Mandarin*, First Edit. Selangor: MySkill Media Sdn Bhd, 2010.

[4] M. A. Ab Wahid, *Manis-Manis Si Limau Mandarin*, Mac. Jabatan Pertanian Malaysia, 2016.

[5] D. M. Beckles, "Factors affecting the postharvest soluble solids and sugar content of tomato (Solanum lycopersicum L.) fruit," *Postharvest Biology and Technology*. 2012.

[6] S. R. Delwiche, W. Mekwatanakarn, and C. Y. Wang, "Soluble solids and simple sugars measurement in intact mango using near infrared spectroscopy," *Horttechnology*, 2008.

[7] N. Mat Nawi, G. Chen, T. Jensen, and S. A. Mehdizadeh, "Prediction and classification of sugar content of sugarcane based on skin scanning using visible and shortwave near infrared," *Biosyst. Eng.*, 2013.

[8] N. C. T. Mariani, R. C. Da Costa, K. M. G. De Lima, V. Nardini, L. C. Cunha Júnior, and G. H. D. A. Teixeira, "Predicting soluble solid content in intact jaboticaba [Myrciaria jaboticaba (Vell.) O. Berg] fruit using near-infrared spectroscopy and chemometrics," *Food Chem.*, 2014.

[9] D. Kimball, "Brix and Soluble Solids," *Citrus Process.*, pp. 7–33, 1991.

[10] K. Kato, "Electrical Density Sorting and Estimation of Soluble Solids Content of Watermelon," *J. Agric. Eng. Res.*, vol. 67, no. 2, pp. 161–170, 1997.

[11] C. V. K. Kandala, C. L. Butts, and S. O. Nelson, "Determination of moisture content of in-shell peanuts by parallel-plate impedance measurements in cylindrical sample holder," *Sens. Instrum. Food Qual. Saf.*, vol. 1, no. 2, pp. 72–78, 2007.

[12] C. V. K. Kandala, C. L. Butts, and M. C. Lamb, "Moisture Content Determination for In-Shell Peanuts with a Low-Cost Impedance Analyzer and Capacitor Sensor," *Trans. ASABE*, vol. 51, no. 4, pp. 1377–1381, 2008.

[13] C. V. Kandala and N. Puppala, "Parallel-plate capacitance sensor for nondestructive measurement of moisture content of different types of wheat," *2012 IEEE Sensors Appl. Symp. SAS 2012 - Proc.*, pp. 68–72, 2012.

[14] M. Soltani, R. Alimardani, and M. Omid, "Prediction of banana quality during ripening stage using capacitance sensing system," *Aust. J. Crop Sci.*, vol. 4, no. 6, pp. 443–447, 2010.

[15] V. Bewick, L. Cheek, and J. Ball, "Statistics review 7: Correlation and regression," *Crit. Care*, vol. 7, no. 6, pp. 451–459, 2003.

[16] P. Berens, "CircStat: A MATLAB Toolbox for Circular Statistics," *J. Stat. Softw.*, vol. 31, no. 10, pp. 1–21, 2009.

[17] C. Jarén, J. C. Ortuño, S. Arazuri, J. I. Arana, and M. C. Salvadores, "Sugar Determination in Grapes Using NIR Technology," *Int. J. Infrared Millimeter Waves*, vol. 22, no. 10, pp. 1521–1530, 2001.

[18] M. N. Latifah, O. Fauziah, and Y. Talib, "Effect of packing methods on the quality of minimally processed green citrus cv . limau madu," vol. 36, no. 1, pp. 69–75, 2008.