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Non-destructive Analysis of Pamelo Citrus Fruit Maturity with Impedance Spectroscopy Method

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Abstract— Citrus fruit is a fruit that is favored by the public. The quality of the fruit from the garden to the consumer goes through a long process. Generally, the quality of the fruit is evaluated by a visual judgment ratio that can be wrong. This method also only evaluates the external quality of the fruit. The internal quality of the fruit such as sugar content is determined by a refractometer which belongs to the destructive method, and is not suitable for online quality measurement. A non-destructive and objective method to evaluate the quality of citrus fruits is needed. Electrical Impedance Spectroscopy (EIS) method can be used in non-destructive investigation. In this study, a non-destructive measurement of pamelo orange fruit was developed. The impedance change of pamelo citrus fruits during ripening was observed over a period of one week. The impedance of pamelo orange fruit was measured by AD5933 evaluation board and then the measurement data was analyzed by EIS Spectrum Analyzer software. Frequency-related electrical characteristics were observed, the results showed that the electrical impedance decreased and the phase increased.

Keywords: Electrical Impedance Spectroscopy (EIS), Impedansi, Phase, AD5933 and Ripening of pamelo.

1. Introduction

Citrus fruit is a fruit that is favored by the wider community because it tastes good, refreshing and can help supplement vitamin needs in the body. The way people consume citrus fruits varies depending on the type of citrus fruit, some are consumed directly, taken juice or made into processed food[1]. Citrus fruits that have high quality can compete in the global market. It usually has an attractive skin colour, a sweet taste, and has few or no seeds [2].One of the most popular citrus fruits is pamelo. Pamelo Nambangan is favoured for its unique fruit characteristics that are in line with consumer tastes, the colour of the flesh is pink, fresh sweet and sour taste with a hint of tartness and little or no seeds. In addition, its storage capacity is also quite long, ranging from two to three months, making it possible for longer marketing distribution to outside the island and abroad. [3].

Fruit quality from the garden to the consumer goes through a long process. Storage, handling and transport are important factors that determine production and consumer demand [4]. Generally, the quality of the fruit is evaluated by a visual judgement ratio, which can be wrong. This method also only evaluates the external quality of the fruit. The internal quality of these fruits such as sugar content

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is determined by refractometer which belongs to destructive method, and is not suitable for online quality measurement. Therefore, a non-destructive and objective method to evaluate the quality of citrus fruits is needed [5]. Non-destructive methods are highly desirable to avoid food waste and the possibility of real time decision support [4]. One of the properties that can reflect the quality of the fruit can be observed from the electrical properties, namely the electrical impedance present in the fruit.

Electrical Impedance Spectroscopy (EIS) is an electrical impedance analysis technique that has been applied as a non-destructive investigation in a number of research fields.` EIS has also been widely used in agriculture, plant physiology, food engineering to study various food products such as fruits like Banana [6], [7], Nectarine, Persimmon, Apple, Kiwifruit, Mango [8], avocado [9], [10], Garut citrus fruit,[11], and cucumber vegetables [7], to measure the electrical impedance of biological tissues as a function of frequency. Changes in composition, anatomy, physiology of biological tissues, changes in bioimpedance and other electrical properties [12]. A sinusoidal test voltage or current is applied to the sample under test to measure its impedance over a suitable frequency range. EIS is a powerful technique for investigating the electrical properties of a wide variety of materials [13].

Previous research made a test tool for the ripeness of pamelo oranges using the impedance method [14]. However, the study only measured the electrical impedance of 5 different fruits at a time. It has not explored the characteristics of impedance changes during pamelo orange ripening. This study will measure the electrical impedance of pamelo fruit during ripening using impedance spectroscopy method. The device used in this research is AD5933 Evaluation Board, then fitting the measurement data is done using EIS Spectrum Analyser software.

2. Method

The hardware used in this research consists of 1 AD5933 device as an impedance converter, and is connected to a PC using a Mini-USB cable through the available port and connected to i2c. Two Ag/AgCl electrodes were attached to the pamelo orange fruit and connected to the AD5933 device using a 75 Ω coaxial cable with a crocodile connector at the end. The device installation process is shown in Figure 1.

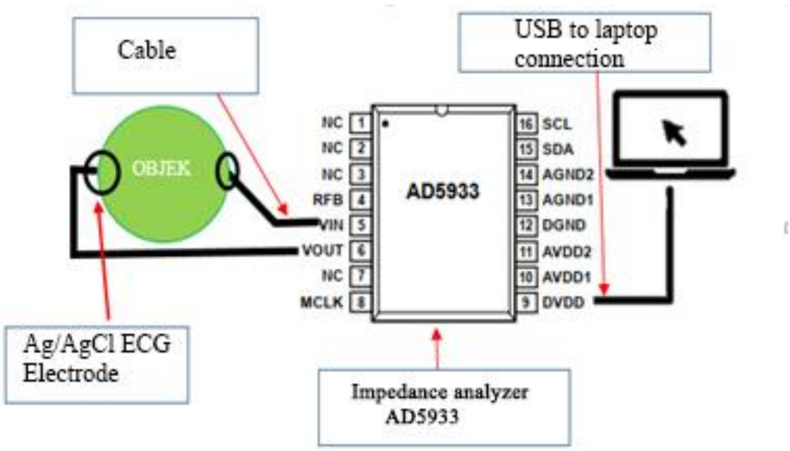

Figure 1. Hardware Design

The measurement process of the impedance value of pamelo orange fruit consists of several stages illustrated in Figure 2. With the AD5933 device, impedance measurement can be done directly using only a computer or laptop device and the AD5933 device. The stages of measuring the impedance of pamelo orange fruit with AD5933 begin with determining the feedback resistor (RFB) and calibration resistor (Rcal). Next, set the measurement parameters on the AD5933 software such as initial frequency, frequency increment and other parameters. Before taking measurements on pamelo orange fruit, the AD5933 device must be calibrated first with either a resistor, capacitor or complex circuit. The component used for calibration in this study is a resistor because the impedance value of the resistor is the same as the value of the resistor. Make sure that the calibration impedance value is the same as the value of the Rcal component before saving the measurement data on a computer or laptop. Calibration measurement data is saved as a reference to determine the phase angle (ZØ). After calibration, the impedance measurement of pamelo orange fruit can be done without changing the settings in the AD5933 programme. The measurement results are processed using Microsoft Excel to find the phase value (ZØ), Real number (Re) and Imaginary number (Im). Then the results of data processing are saved with the Notepad programme as data used for matching or fitting using the EIS Spectrum Analyzer.

Figure 2. Flowchart of pamelo orange impedance measurement with AD5933.

The AD5933 board has interface software that controls operation and data processing. The software has a very important role to perform a frequency sweep in the process of sampling impedance data. In the measurement process, users can set the measurement start frequency, frequency increment, and end frequency. Users can also set the total measurement points of the frequency range. In adjustment to the frequency, the user can also adjust the excitation voltage, gain factor and the user can view the impedance and phase measurement results of the sample. Users can download the measurement results to save and analysis on a computer or laptop.

After the calibration, the impedance measurement of pamelo orange fruit can be performed without changing the settings in the AD5933 program. The measurement results were processed using Microsoft Excel to find the phase value (ZØ), Real number (Re) and Imaginary number (Im). Then the results of data processing are saved with the Notepad program as data used for matching or fitting using the EIS Spectrum Analyzer.

EIS Spectrum Analyzer is a programme for impedance spectrum analysis and simulation. The programme's analysis method is based on the PDEIS (potentiodynamic electrochemical impedance

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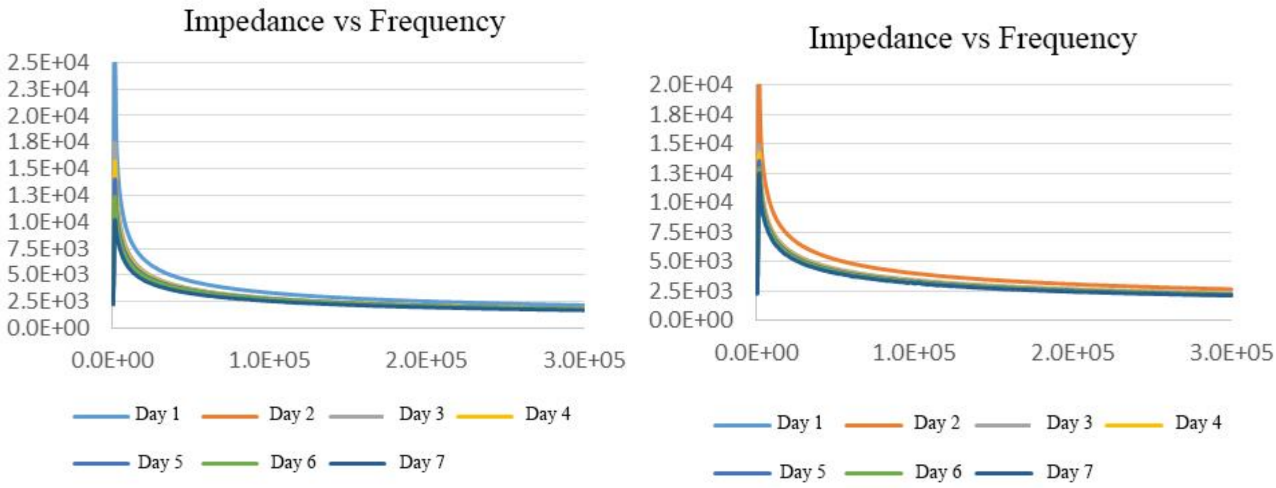
spectroscopy) spectrometer algorithm. In the original (potentiodynamic) version the analysis of impedance data is applied to 3D spectra and provides a link between the AC response components at the electrode potential. The programme has been adapted to solve various tasks in general (stationary) impedance spectroscopy.

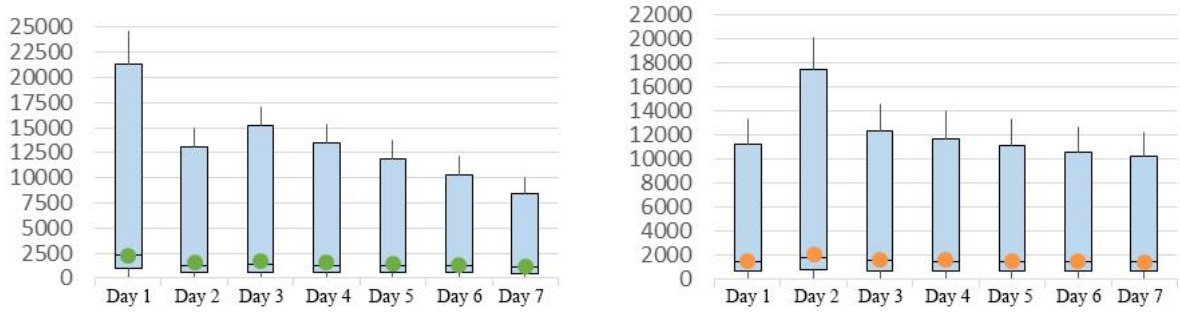
3. Result and Discussion

The measurement of pamelo orange fruit was carried out for 7 sequential days with a voltage of 2Vpp frequency range of 1000 Hz to 300 kHz, 1000 Hz increments with a total of 300 measurement points. The frequency range used aims to try to measure pamelo oranges in frequency-dependent dispersion regions that are in the α-dispersion region (low frequency) and in the β-dispersion region (mid frequency). Measurements were taken at room temperature and measured every 8am. Citrus fruit A was unripe and citrus fruit B was almost ripe. Figure 3(a) shows the impedance value changes that occurred over 7 days in sample A, while Figure 3(b) shows the changes in sample B.



(a) (b)

Figure 3. Impedance change (a) citrus sample A and (b) citrus sample B



(a) (b)

Figure 4. Impedance box plots (a) citrus sample A and (b) citrus sample B

The ripening of pamelo oranges by electrical impedance spectroscopy method using EIS has an average impedance result that continues to decline for 7 days of measurement. The average impedance measurement on citrus fruit A with immature conditions at the time of picking is 3556∠-34.25° Ω, and during 7 days of measurement the impedance value drops to 2606.19∠-29.82° Ω with an average decline of 158.36∠-0.74° Ω. While the average impedance measurement on citrus fruit B

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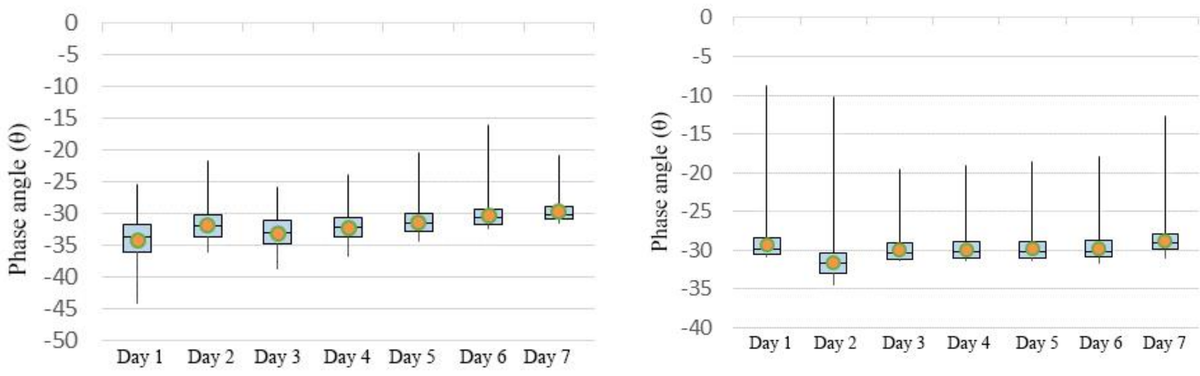
with a condition that is almost ripe at the time of picking is 3632.53∠-30.3° Ω, and during 7 days of measurement the impedance value drops to 3172.04∠-28.72° Ω with an average decrease of 76.75∠-0.26° Ω.

Fruit bio-impedance measurements contain real (R) and imaginary (X) parts, therefore phase (θ) is the second important parameter after impedance in bio-impedance measurements. Figure 5 shows the phase change during the measurement. In contrast to the impedance, the phase angle has increased, this is shown by the average value of the phase angle change on each day which has increased even though the increase has not increased significantly.



(a) (b)

Figure 5. Box plot of phase changes (a) citrus sample A and (b) citrus sample B

After receiving the measurement data, the next process is fitting the measurement data with EIS Spectrum Analyser software. Fitting the measurement data using the equivalent circuit of citrus fruits developed. Measurement data can be obtained by fitting the parameters of the constituent components shown in Figure 6.

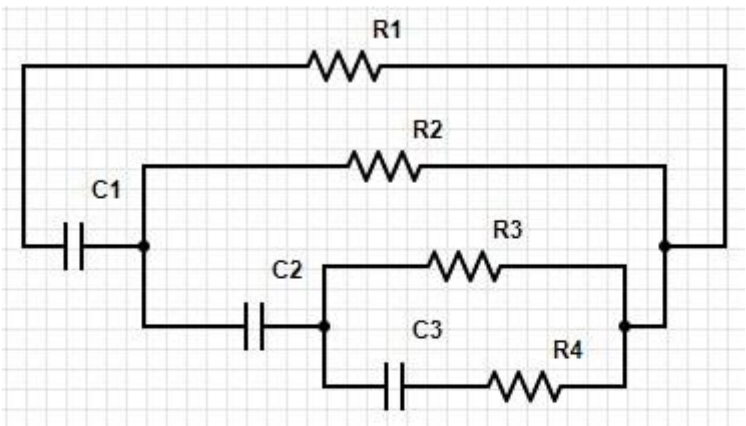


Figure 6. Pamelo orange equivalent circuit modelling

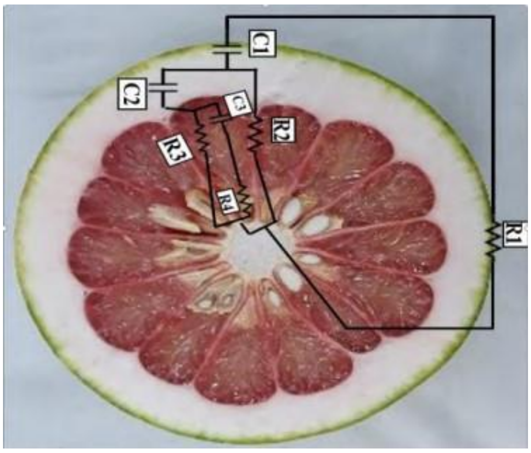


Figure 7. Visualisation of pamelo orange equivalent circuit

The equivalent circuit of Figure 7 shows that pamelo orange has resistance and capacitance components. The resistance component of the fruit consists of (seed, R4; segment, R3; segment wall, R2; and outer skin wall, R1) and its membrane capacitance (segment, C3; albedo, C2; and flavedo, C1). Figure 8 shows the results of visualising the equivalent circuit into a pamelo orange.

Table 1 and Table 2 show the approximate components that make up the measurement data on each pamelo fruit sample.

Table 1. The components that made the circuit equivalent to pamelo orange A.

Day to	Parameter	C1	C2	C3	R1	R2	R3	R4
1	Value	2.07E-9	5.45E-10	1.50E-10	32054	6656.1	4248.5	3767.5
	Error (%)	0.77	0.72	1.33	1.36	0.48	0.63	1.7312
2	Value	2.36E-09	6.20E-10	1.74E-10	17360	5950.5	3791.4	3439.8
	Error (%)	0.69	0.61	1.12	0.74	0.41	0.53	1.3807
3	Value	2.33E-09	6.17E-10	1.77E-10	19952	5757.1	3699.7	3263.7
	Error (%)	0.69	0.63	1.17	0.88	0.42	0.56	1.4794
4	Value	2.23E-09	6.10E-10	1.74E-10	17403	5791.6	3734.6	3317.4
	Error (%)	0.70	0.63	1.17	0.78	0.42	0.56	1.4794
5	Value	2.27E-09	5.96E-10	1.72E-10	14957	5813.5	3765.9	3395.3
	Error (%)	0.71	0.63	1.18	0.68	0.42	0.57	1.4866
6	Value	2.15E-09	5.71E-10	1.67E-10	12666	5792.6	3787.6	3519.2
	Error (%)	0.71	0.63	1.24	0.58	0.42	0.58	1.5426
7	Value	1.89E-09	5.30E-10	1.62E-10	9829.9	5154.9	3519.9	3598
	Error (%)	0.75	0.74	1.66	0.55	0.48	0.72	2.0531

Table 2. The components that made the circuit equivalent to pamelo orange B.

Day to	Parameter	C1	C2	C3	R1	R2	R3	R4
1	Value	2.11E-09	4.94E-10	1.38E-10	17826	7605.7	4845.5	4379
	Error (%)	0.81	0.61	1.15	0.57	0.42	0.54	143
2	Value	1.79E-09	4.23E-10	1.18E-10	23396	8615.5	5255.9	4560
	Error (%)	0.87	0.69	1.28	0.85	0.48	0.62	1.74
3	Value	1.99E-09	4.66E-10	1.33E-10	16110	7595.4	4750.5	4273.7
	Error (%)	0.82	0.64	1.22	0.62	0.44	0.58	1.57
4	Value	1.98E-09	4.74E-10	1.36E-10	15375	7520.2	4664.8	4251.4
	Error (%)	0.81	0.64	1.22	0.60	0.44	0.58	1.54
5	Value	1.98E-09	4.82E-10	1.40E-10	14642	7442.3	4579.2	4231.3
	Error (%)	0.83	0.65	1.25	0.59	0.46	0.59	1.56

6	Value	1.98E-09	4.91E-10	1.43E-10	13912	7359.9	4493.1	4214.6
	Error (%)	0.87	0.68	1.34	0.61	0.48	0.62	1.63
7	Value	1.86E-09	4.92E-10	1.47E-10	10815	7219.5	4382.2	4265.9
	Error (%)	0.81	0.67	1.43	0.49	0.48	0.62	1.67

The wall resistance of fruit A, which at the time of picking was still in an unripe condition, had a higher resistance component value (R1-R4) than fruit B, which at the time of the picking was already yellowish in colour. The resistance value in the outer wall represented by R1 decreased during the 7 days of measurement, just like the state of the citrus fruit peel which is getting wrinkled from the first day of the picking to the last day of measurement. The resistance value of the orange seed represented by R4 has the smallest value and is almost the same as the resistance value of the orange segment represented by R3.

The Pamelo orange has poor electrical conductivity in general, especially at low frequencies. However, when the frequency is increased, so is the conductivity. When the frequency is changed, changes in tissue resistance and membrane capacitance reflect changes in ion mobility and polarity shifts in the cells. Electric current can flow or penetrate the cell after the frequency is increased, which is confirmed by the fact that the measurement results show low and stable impedance values, while at low frequencies and only extracellular passages are characterised by higher impedance.

4. Conclusion

The ability of the AD5933 device to measure impedance is very good, the measurement results depend on the settings of the feedback resistor (RFB) and calibration resistor (Rcal). The electrical characteristics related to frequency have been observed in the measurement of Pamelo Citrus for 7 days, and the results reveal that the electrical impedance decreases and the phase increases. Pamelo orange has poor electrical conductivity in general, especially at low frequencies. However, as the frequency increased, so did the conductivity, the changes in tissue resistance and membrane capacitance reflecting changes in ion mobility and polarity shifts in the cells. Measurements over a longer time span and a larger number of samples need to be taken to non-destructively verify the pamelo orange measurements.

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