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A STUDY ON ELECTRICAL IMPEDANCE IN RIPENING AMBON-BANANAS (MUSA PARADISIACA VAR. SAPIENTUM) PROCESSES STIMULATED BY ETHREL (2-CHLOROETHYL PHOSPHONIC ACID)

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ABSTRACT: The use of ethrel (2-chloroethyl phosphonic acid) is faster fruit maturity. Excessive use of ethrel in the ripening of bananas causes damage to the fruit and people who consume it. The principle of measurement based on electrical impedance spectroscopy can detect changes that occur in biological material. This paper discusses the comparison of the electrical impedance values of the ripeness of bananas, which marinated using various ethrel concentrations and natural maturity. The electrical impedance measurement system uses four needle electrodes made of pure silver, which are supported by the use of the V to I module and signal generator from PICOSCOPE 5244B. The system injects a current of one mA into the sample. The sample consisted of bananas through the ripening process using three ethrel concentrations of 1000 ppm and 2000 ppm. Observation of changes in fruit and impedance measurements in the range of 1 Hz to 1 MHz carried out every two days for nine days. The impedance value that correlates with the maturity of the banana well observed in the frequency range between one to 100 kHz. Increasing the impedance value describes the fruit maturity, which indicated by increasing the acidic until peak-phase and increasing sugar content until the fruit rot. The maturation process using ethrel provides the effect of shifting the peak impedance value. The higher the ethrel concentrations that used the electrical impedance value of the banana will be higher.

Keywords: Electrical Impedance, Bananas, Ethrel

1. INTRODUCTION

Consumer attention to healthy food products is still a concern until now, while food producers are trying to find a profit that is as big as possible. Processing products that are faster and cheaper is still the choice of producers, although it has the potential to harm consumers in terms of health. One of the processes used by traders is to speed up the ripening of bananas using ethrel (2-chloroethyl phosphonic acid).

Some studies use ethrel in the process of accelerating fruit with observations based on physiological changes in the fruit. The ethrel mango ripening at a dose of 1000 ppm, gives a good taste and is still acceptable to the market [1], etrel spray effect on postharvest mango with a different concentration of 600 ppm accelerates uniform maturation in 4 days [2], at maturation of Guava [3], maturity of winter tomato fruit harvested [4]. Physiological changes in biological media (e.g., fruits) indicate a difference in the properties of these materials. Changes in the properties of compositions that affect the electrical properties observed using a system of electrical impedance spectroscopy (EIS).

The EIS-based study has been applied to various fields, for example, observing changes in physiological properties in fruits: apples, mango, bananas, and avocado [5–9]. Also, the EIS application used to detect additives, or additional food ingredients identify the concentration of salt solutions [10–14]. Until now, various forms and quantities of EIS electrodes have been developed [15, 16].

The study aimed to apply EIS to Ambon banana with a ripening process using various concentrations of ethrel. Electrical parameters obtained from measurements clarified with maturity observed from changes in skin color.

2. MATERIAL AND METHODS

2.1 Samples of Bananas Ambon

Ambon banana (Musa paradisiaca var. Sapientum) obtained from the local market. The selection of bananas based on its size and the banana fruit washed thoroughly.

Banana fruit includes climacteric fruit, which has a different sudden period where during this process, a series of biological changes occur, beginning with the formation of ethylene [17], as shown in Fig. 1. The ripening process starts with the occurrence of cell metabolism that develops towards the beginning of the ripening process

(Climacteric Respiration Minimum phase). At that time, acid formation dominated the banana starch. After going through the minimum Climateric Respiration phase, the transformation of starch into sugar occurs, the transformation of tannin compounds which can dissolve into insoluble forms, a significant reduction in the amount of acid, softening of woody tissue and increasing fluid levels.

The grouping of Ambon Banana used as a sample based on the treatment group and labeled. The treatment on bananas using ethrel carried out on day 0 for each concentration at room temperature, by dipping the banana into a container containing ethrel solution for 30 seconds then remove it and stored without cover for nine days. Physiological observation of banana skin carried out on the first, third, fifth, seventh, and ninth days.

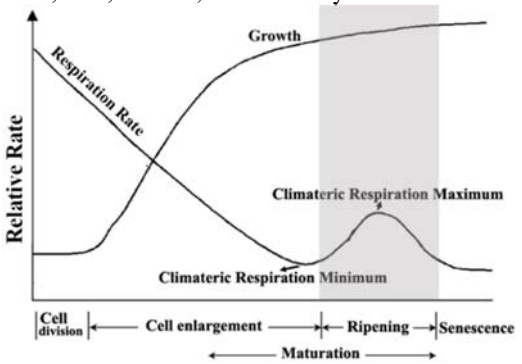

Fig. 1 Generalized patterns of growth and respiration during development, maturation, and senescence of climacteric fruits.

2.2 Electrical Impedance Measurements

The EIS system consists of four silver needle electrodes with a diameter of 1 mm ((length of 10 mm), two electrodes used to inject current (3.6 mm apart) and two others used for measuring the output voltage (8 mm distance). Picoscope type 5244B supports the system as an AC voltage generator, and the injection of 1 mA sinusoidal current in a banana sample uses a V to I converter circuit, as shown in Fig 2.

Measurement of electrical impedance in the frequency range of 1 Hz to 1 MHz using needle electrodes by plugging all parts of the needle electrode into the middle part of the banana. Impedance measurements carried out in room conditions (temperature, humidity, and atmospheric pressure). The data obtained is the value of the output voltage. Calculation of the impedance value by dividing the number of tops and bottom peak voltages, and then the results divided by a current of 1 mA. Calculation of phase difference from input and output voltages by measuring the difference in peak voltage displacement from input and output.

The research subject in the form of biological material is usually analogous to an electrical circuit, which consists of resistors and conductors, and there can be inductors depending on the content. The electrical impedance of banana, like any other plant tissues, does not contain any inductive components but consists of the resistive and capacitive elements [18], as shown in Fig. 3.

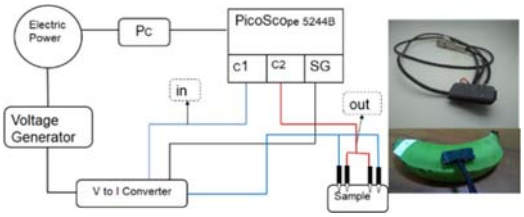

Fig. 2 System of Electrical Impedance Measurements

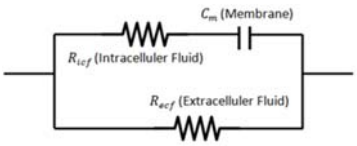

Fig. 3 Equivalent circuit model based on cell tissue according to the modified Hayden Model, C_m is Capacitance of the membrane, R_{ecf} is the resistance of apoplectic fluids, and R_{icf} is intracellular resistance [6, 19].

Analysis of the effect of frequency on impedance by application Bode plot to determine the extent of the impact of phase difference on real value and imaginary impedance to frequency. Effect of ethrel treatment by applying the Nyquist curve, as shown in Fig 4.

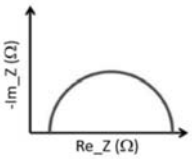

Fig. 4 Nyquist plot analysis for the modified Hayden Model

3. RESULTS AND DISCUSSIONS

3.1 Ethrel Effect on Banana Skin Color

Ripening of bananas using ethrel affects the maturity of bananas. Observations on the physiological properties of color, it appears that the yellow color of the fruit skin shows the level of sophistication, the faster it forms in the immersion of 2000-ppm ethrel, as shown in Fig. 5. Control banana (natural ripening process) in 9 days still

shows greenish-colored skin, and different results occurred in bananas with a concentration of 1000-ppm ethrel, which was yellow on the fifth day, while an ethrel concentration of 2000 ppm caused a more yellow color to occur on the third day.

The characteristic of the maturity of a banana is that the skin color of the fruit changes from green to turn yellow with the increasing formation of ethylene gas. During the ripening process of bananas, there is an increase in sugar levels and a decrease in flour content or softening of banana meat. This condition causes by an insoluble remodeling of the protopectin to become soluble. These substances are derivatives of Polygalacturonic acid and are present in the form of protopectin, pectin, pectinic acid, and pectic acid. When the fruit ripens, the soluble pectate and pectinate content increases, while the total amount of pectate decreases. In the change in pectin, the fruit's toughness decreases, so the fruit becomes soft. Hydrolysis Amylum is perfect by acids or specific enzymes on polysaccharides producing mono-saccharides or their derivative compounds, and there is a slight increase in sucrose, glucose, and fructose during maturation.

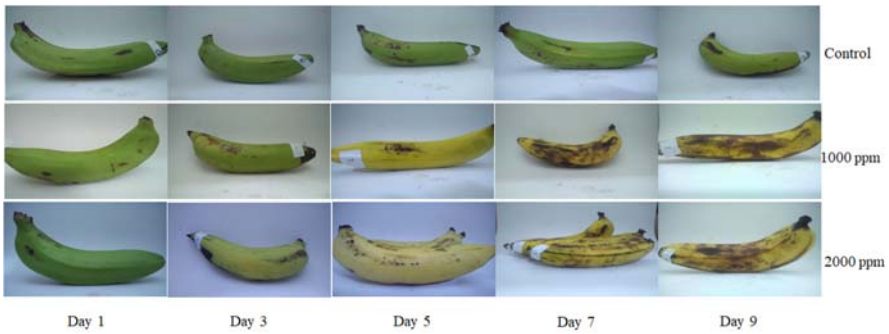

Fig. 5 Display of banana color for all days at various ethrel concentrations.

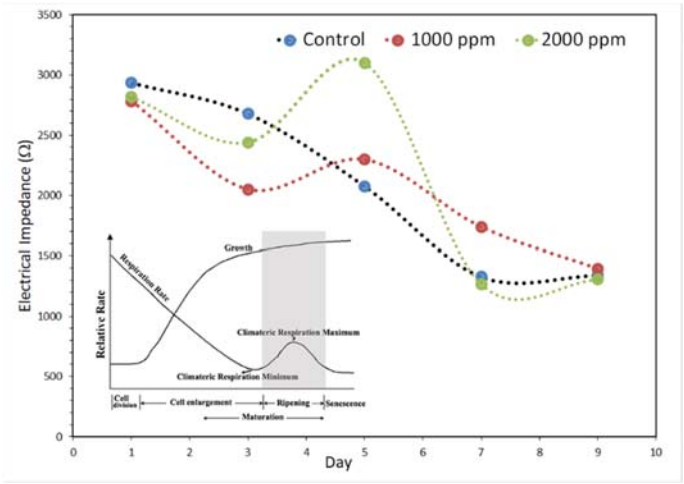

Fig. 6 Plot Graph of electrical impedance measurements at a frequency of 100 Hz in various concentrations, the results compared with climacteric fruit charts.

The results showed a similar pattern, where the impedance value suddenly decreased with increasing time, as shown in Fig. 6. The maturation process in the control sample until the ninth day passes through the minimum climacteric maturation phase and will lead to the formation of sugar. The measurement results show a decreasing impedance value until the minimum climacteric respiration phase.

The formation of sugar in the ripening process will increase the impedance value of the banana [14]. The 1,000 ppm ethrel concentration shifted the time of sugar formation compared to the control, where on the third day, the maximum maturity level occurred, and this also happened at a concentration of 2000 ppm. After the peak phase, the process will enter the hydrolysis phase, where this phase will reduce the impedance value. The interesting thing happens is that at a concentration of 2000 ppm there is a sharper decline compared to 1000 ppm, the hydrolysis process occurs more so that the banana decomposes more quickly.

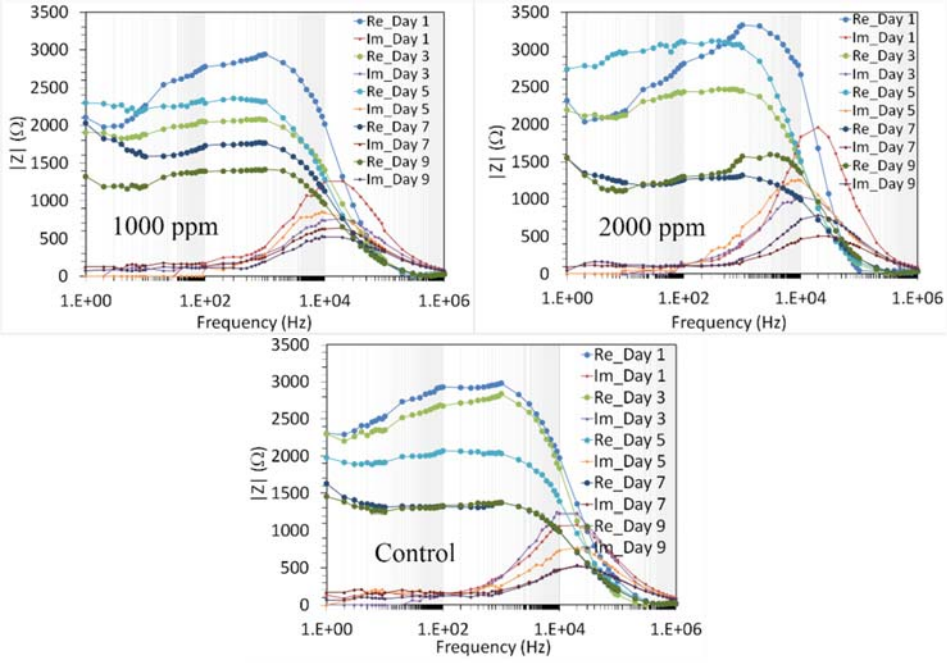

Fig. 7 An analysis of Bode-plots results for real and imaginary of impedance values in all treatments.

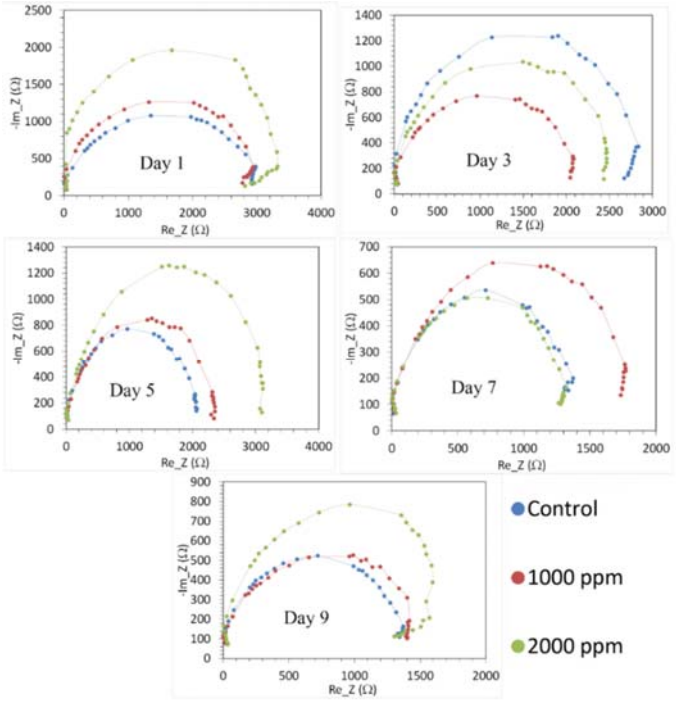

Fig. 8 The results of the Nyquist plot analysis for all treatments.

Fig. 7 shows the Bode plots for all treatment, where at low frequencies (up to 100 Hz), all graphs show a relatively constant phase angle, and the impedance value shows a linear relationship. Dispersion occurs at a frequency of 1000 Hz and above. At that time, the impedance value more influenced by the presence of resistive and capacitive properties of the material.

Plotting Nyquist curves show apparent differences between treatments for all days. Suitability between extractions results for each element obtained with the model used is very high, as shown in Fig. 8.

The measurement on the first day proved a shift

in the imaginary-value and real value of electrical impedance as the concentration of ethrel increased and at 2000 ppm shifted further.

On the third day, a noticeable change occurred in bananas with an ethrel concentration of 2000 ppm, where there was a shift in the real and imaginary values of electrical impedances. Whereas, the result for a 1000 ppm shifts only its imaginary-value. As shown in Table 1, the error is around 7.5% for all elements in all treatments, where the lowest error is 1.24%, and the biggest is 21.70%.

Table 1 The simulation results using EIS Spectrum Analyzer Freeware [20] for the equivalent circuit in Fig. 3, with the fitting of the Nyquist plot results in Fig. 8.

Day	Element	Control	1000	2000
1	R_{icf} (Ω)	50.57	50.93	50.64
	Error (%)	18.20	16.63	21.70
1	C (nF)	3.22	3.07	2.11
	Error (%)	3.58	3.58	11.00
1	R_{ecf} (Ω)	2986.90	2914.00	3307.60
	Error (%)	2.30	1.52	1.24
3	R_{icf} (Ω)	50.19	50.21	50.55
	Error (%)	6.78	10.19	5.33
3	C (nF)	3.30	3.72	3.33
	Error (%)	3.01	3.43	16.06
3	R_{ecf} (Ω)	2756.50	2015.40	2470.30
	Error (%)	2.13	3.30	1.94
5	R_{icf} (Ω)	50.77	50.77	50.21
	Error (%)	10.06	7.18	6.86
5	C (nF)	3.72	3.72	3.69
	Error (%)	3.84	19.04	9.48
5	R_{ecf} (Ω)	2323.60	2323.60	3078.20
	Error (%)	10.99	2.80	3.07
7	R_{icf} (Ω)	50.68	50.02	50.09
	Error (%)	7.09	7.98	7.23
7	C (nF)	3.83	3.79	3.86
	Error (%)	9.80	14.77	5.81
7	R_{ecf} (Ω)	1367.00	1802.00	1289.30
	Error (%)	3.52	2.29	3.52
9	R_{icf} (Ω)	50.69	50.76	50.76
	Error (%)	8.51	14.96	14.96
9	C (nF)	3.84	3.73	3.73
	Error (%)	18.96	6.01	6.01
9	R_{ecf} (Ω)	1353.80	1624.50	1624.50
	Error (%)	2.46	1.48	1.48

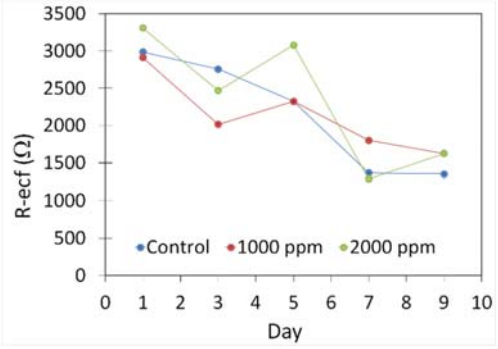

Fig. 9 The value of R_{ecf} obtained by the Nyquist curve at various concentrations from Table 1.

The value of C is relatively constant at around 3.5 nF, and similar results obtained for the R_{icf}, which is approximately 50.5 Ohm. On the other hand, R_{ecf} results of the curve tend to follow the maturation level of bananas, as shown in Fig 9. The extraction results for all elements in all treatments turned out to be similar to the curves of the measured electrical impedance values, as shown in Fig, 6. Changes in the composition of ingredients in the ripening process of bananas, for example, sugar content, acid content, salt, amount of liquid due to hydrolysis affect the resistivity level of the material.

4. CONCLUSION

Ethrel stimulation accelerates the ripening process of Ambon banana fruit. On the fifth day, bananas with ethrel have reached the maximum climatic respiration phase, while natural fruit ripening is still in the minimum climacteric respiration phase. Impendence spectroscopic system can detect banana ripening process, where on a fifth day of maturation due to 2000 ppm ethrel has a maximum impedance value of 3101.83 Ω higher than 1000 ppm with an impedance value of 2297.67 Ω. The electrical impedance value during the ripening process of bananas is more influenced by the nature of extra cell fluid resistance due to the formation of sugar solution which has resistive properties, with resistance values at the maturity peak of 3078.60 Ω and 2323.6 Ω for 2000 ppm and 1000 ppm respectively.

5. ACKNOWLEDGMENTS

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