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FRUIT SWEETNESS CHARACTERIZATION USING IMPEDANCE SPECTROSCOPY METHOD

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ABSTRACT

The processing of agricultural products requires technology implementation to increase its production. One way of this technology implementation to increase the production is fruit sweetness measurement, which can be used as a sorting tool of fruit products. The sorting process using this tool can be done with easier way compare than the manual and destructive test. The fruit sweetness is composed of a mixture of sweet molecules fructose, glucose, and sucrose. The measurements of these molecules are usually done with four-point probe and use dc current. In this study, a fruit sweetness characterization using impedance spectroscopy method has been developed and realized, which uses an ac current. By using this method, fruit sweetness level can be characterized based on the impedance measurement on the flesh of a test fruit based on its dielectric properties. The obtained characterization results show that the fruit sweetness level can be measured by the impedance measurement. The obtained impedance is proportional to the concentration of the sweet molecule glucose. This method can characterize the fruit sweetness well and agrees with the calibration result. Therefore, this method can be used to increase agricultural products.

Keywords: fruit, impedance, molecule, spectroscopy, sweetness

INTRODUCTION

As an agricultural country, Indonesia produces many kinds of agricultural products. However, the number of agricultural products from Indonesia is still far behind some other ASEAN countries. The application of technology can be carried out to increase production and added value of agricultural products. Among the agricultural products, a commodity that needs the application of technology in the processing is fruit. The application of technology in fruit processing can maintain the quality of production so that it can increase a significant added value. The quality of processing of fruit commodities can be maintained by sorting the level of maturity or sweetness. This is where the role of technology is to improve the quality of production. The technology applied will replace the manual method that is not practical and efficient, so that the process and quality of production can be more efficient and improved.

The previous research related to the detection of maturity and fruit sweetness is a vision-based method that might apply manual evaluations by trained inspectors to computer vision using modern image acquisition tools such as multi-spectra cameras and high-tech image processing software for object measurement [1-2]. This method is very expensive and not suitable to be applied to small farmers and small-scale agricultural products processing businesses. Another technology that is often used is using sensory panel sense evaluations [3-4]. Soluble sugars in fruits, which consist mainly of glucose, fructose and sucrose [5], can be determined using refractometry or colorimetry [6]. High-performance liquid chromatography (HPLC) is a technique often used for single mixture analysis [7]. Non-structural carbohydrates may be separated and determined using HPLC along with columns and detectors that are suitable for dissolved sugar counters including reflective index detectors (RID), evaporative light scatter detectors (ELSD) and pulse amperometric detectors (PAD) [7-9].

In this study, a system has been designed to characterize the sweetness of fruit, which is intended to determine the level of sweetness of fruit in the processing of agricultural products. Characterization of sweetness in fruit is based on the characteristic impedance caused by molecule of sweetness in the fruit; that are fructose, glucose, and sucrose. But, on the other hand there are factors influencing the taste like acids that affect the liquid impedance of the fruit. Therefore, it is necessary to characterize the effects of these two factors on the sweetness of the fruit.

In the initial stage, only the characterization of the sweetness of sucrose was made to the liquid impedance of fruit flesh. Therefore, sucrose solution is used as the test material. The results of the characterization of the solution are compared and used as references together with the other compounds. The combination of the characterization of the compound solutions are used as a reference in the measurement of fruit sweetness. As a test fruit, mango fruit can be used as sample material in measuring fruit sweetness. Mango fruit is chosen because mango is an agricultural commodity that has a large market share and has high potential for processing agricultural products. In addition, mango have a large amount of fruit flesh, making it easy to conduct impedance characterization.

From the obtained results, the method used could make it possible to characterize the fruit sweetness using ac signal. There many open possibilities that can be used to characterize the sweetness with this ac signal due to reactance properties of the flesh of fruit especially mango.

METHOD

Background of the Application of Impedance Spectroscopy Method

The measurements of the component of sweetness derived from sugar molecules such as monosaccharides have been carried out by many researchers. This measurement is usually carried out by amperometric electrochemical methods using four electrodes and is carried out using a DC current. This measurement does not provide complete information so it needs to be improved by using the other method that provides information such as responses to changes in frequency. The old measurement method also cannot distinguish sweet compounds between the three components of sweetness in the fruit so that it cannot be used as a method of measuring the sweetness in precise. Besides, measuring with DC currents for acidic compounds also does not provide complete information compared to measurements using spectroscopic methods and could cause polarization in the solution.

Characterization of sweetness compounds in fruit is expected to be optimal if using AC current. With this, an impedance response of the material tested for the given frequency will be obtained. The resulting response can be more informative because it records the influence of varied frequencies so that the response from the characterization of the molecules of sweetness and also sour taste can be distinguished. The difference in the arrangement of chains of molecules making up sweet and sour taste will cause differences in the dielectric properties of the solution so that in the end it will affect the impedance of the solution containing the molecule of the sweet and sour taste.

Impedance Spectroscopy Method

Impedance spectroscopic methods are often used to analyze a solution that can be considered to have a specific dielectric value. A solution consisting of water and specific molecules are conductive so that it can conduct an electric current. This solution is analogous to a capacitor that has a specific dielectric value that is influenced by the molecules making up the solution. A solution analogous to a capacitor can be described by an equivalent circuit as in FIGURE 1.

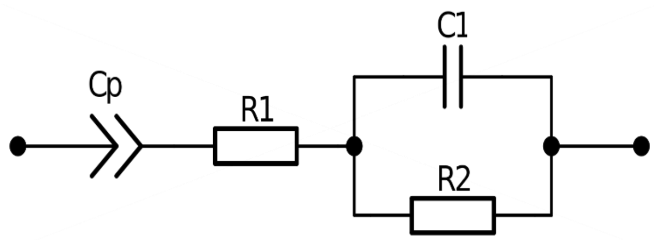

FIGURE 1. The equivalent circuit of solution.

The existence of resistors and capacitors in the equivalent circuit will cause the circuit to be reactive. The circuit will have a different response to frequency variations. Cp shows the polarization capacitance at the electrode [10], R1 is the representation of high frequency resistance, and the combination R2-C1 is the solution or sample analyzed [11-13]. The capacitor in the circuit will cause a decrease in impedance along with the increase in frequency. From this trait it can be predicted that the solution impedance will decrease with increasing frequency.

Platinum metal is used as an electrode to prevent a reaction between the solution and the electrode. This is because metal platinum is inert and only used as a conductor of electrons in the reaction. An ac voltage signal is injected into the solution with varying frequencies. The voltage and current signals contained in the electrode are acquired for impedance calculations. Where the impedance equation used is as follows [14]:

$$Z = |Z| e^{j\varphi} \tag{1}$$

where |Z|is the absolute impedance |Z|=((|V|)/(|I|)) and φis the phase difference between the voltage and the current.

Measurement System

Electrode

Two platinum wires with 0.5 mm diameter, a length of 5 mm, and a distance of 2 mm were used as the electrodes. The designed electrodes are quite small, so they can be easily injected into the fruit flesh when making the measurements. The fruits measured do not need to be damaged or destructed by peeling, but are only pierced to a maximum of 5 mm. Thus, the measurement with this electrode is almost said to be non-destructive. The electrode geometry used looks like a sketch in FIGURE 2.

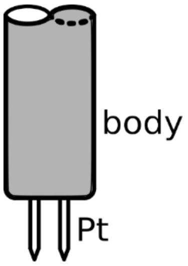

FIGURE 2. Electrode's geometry.

Electronics System

As an initial design, the system needed is a processor that processes the signal from the injected voltage and the current obtained from the solution. The signal source and data acquisition system originated and was carried out by a data acquisition (DAQ) card from National Instruments (NI) with a type of PCI-6221, which has analog I/O for analog input and output. For signal processing, a buffer is needed for the injected voltage and a current to voltage converter to convert the current to a voltage, so that it can be directly acquired by the card. The block diagram of the measurement system looks like in FIGURE 3.

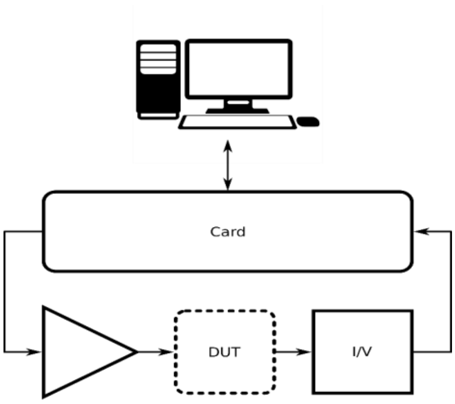

FIGURE 3. Block diagram of characterization system.

From the block diagram above, the analog voltage signal originating from the card is amplified and used as a reference voltage of an amplifier. From the amplifier, the voltage is injected into the solution or device under test (DUT). The current arising from the impedance of the solution is converted to the voltage by a current to voltage converter for the acquisition process. The injected voltage and the voltage representing this current are acquired with the card for signal processing. For this purpose, we need an analog output voltage channel (analog output - AO) and two analog input voltage channels (analog input - AI) on the card. The card used has a 16-bit analog output voltage and input resolution specification, 833 and 250-kilo samples per second (ksps) for (AO) and (AI), respectively.

The characterization process is run with the program written in LabVIEW software. Impedance measurement uses the Frequency Response Function (FRF) function that is available in LabVIEW software. This function receives voltage and current input signals from an electronic system. The outputs produced by this function are the ratio of the magnitude and the difference of phase of the signal. From this output, the impedance of the solution can be calculated by EQ. 1.

MEASUREMENTS

The *ac* voltage injected into the fruit flesh liquid is set to not be too large, so there will be no major change in the composition of the ion liquid. The maximum permissible voltage depends on the level of liquid ion concentration. In addition, the voltage given is also determined by the ratio between signal and noise. Thus, signal and noise testing needs to be done before characterization. Impedance characterization is carried out up to a frequency of 50 kHz, which is the highest frequency that can be applied due to the limited speed of data acquisition on the card. Usually, the used frequency reaches about 1 MHz [15]. However, the effect of dielectric can still be seen in this applied frequency range. At this stage, the characterization is carried out on a solution of granulated sugar whose molecule is the same as the main molecule making up the sweetness of the fruit, that is sucrose. Measurements start with a low frequency, the frequency is increased by varying steps, which are 1 Hz, 10 Hz, 100 Hz, 1 kHz, and 10 kHz to reach the maximum frequency of 50 kHz.

The measured samples are calibrated using a brix meter to determine the concentration of the contained sugar. The unit of the concentration is in percent and varied with four different values. First is with no sugar at all, and for the three others the sugar concentration is incremented with 10% until 30%. The calibration value for 20% concentration is not achieved as planned due to miss-mixing the sugar into the water, only the concentration of 19% is obtained from calibration with brix meter. Thus, the concentration obtained are 0%, 10%, 19%, and 30%. These four variations are enough, since they could describe the characteristic of an impedance changes in the solutions. The measured impedance value is directly stored in the text file. Then the measurement data is displayed on the graph for analysis.

RESULTS AND DISCUSSIONS

From the measurement results, the effect of the amount of fruit sweetness compound on the measured impedance is obtained. The measured impedance of the solution increases with the addition of the concentration of sugar solution to the sweetness of the fruit. This shows the influence of the addition of sugar molecules on the solution impedance, which causes reduced conductivity. This increase in impedance appears linear with increasing concentration of the solution. At a frequency of around 100 Hz, the impedance in the 0% solution is about 6 kΩ, the impedance in the 10% solution is about 8 kΩ, the impedance in the 19% solution is around 9.5 kΩ, and the impedance in the 30% solution is 12 kΩ. It appears that the impedance has an increase of 2 kΩ for every 10% increase in concentration. The measurement chart is shown in FIGURE 4.

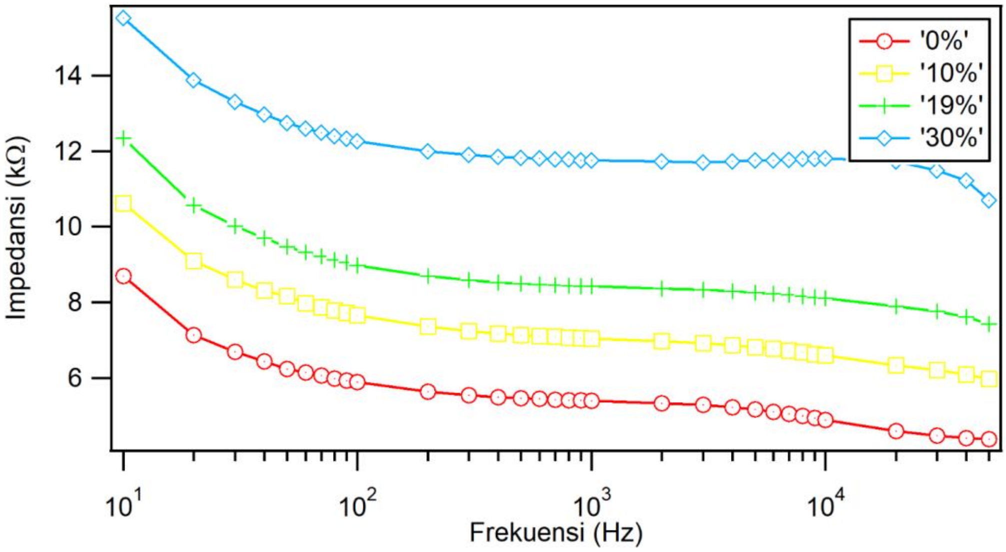

FIGURE 4. Results of impedance measurements on sugar solution composing fruit sweetness.

On the other hand, the measured impedance decreases with increasing frequency given. This indicates the effect of capacitance in the solution or fruit flesh. At high frequencies the capacitance will increase and will cause a sharp decrease in impedance. This appears at a frequency of around 50 kHz, where the decrease in impedance looks different for each concentration. The reason behind the decreases are not exactly known. It could be caused by the influence of the sugar concentration. Further experiments at higher frequency should be performed in order to observe and analyze the phenomena. Therefore, these results can be the reference for a further study of the sweetness measurements.

These results agree with the properties of the molecule, which is the bad conductor for the charges such as ions. Unlike an inorganic molecule, the dissolved glucose molecule in the water cannot create ions because it dissolves as a result of hydrogen bonds. Therefore, the impedance of the solution is proportional to the glucose concentration. This is different with the obtained result from [16], which shows its inversely proportional relation to the glucose concentration in blood. However, it agrees with result obtained by [17-18], which uses the same solution. Based on this results, it can be proved that the method can be used to measure the glucose or sweetness molecules by using the impedance method due to its dielectric properties.

CONCLUSION

From the experiments that have been carried out, an impedance response is consistent with the theory given, where the impedance of the measured solution increases with increasing concentration. In addition, the impedance graph decreases when the measurement frequency is getting bigger, this indicates a capacitance effect that affects the measured impedance of the solution. The measured impedance pattern also changes at high frequencies, and can be used as a parameter to determine the sweetness of the fruit. This results prove that the method is feasible and can be a new method in the simplification of the fruit sweetness measurements.

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