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Novel Impedance Measurement Technique for Soluble Solid Content Determination of Banana

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ABSTRACT

Soluble solid content (SSC) is one of the important traits that indicate the ripeness of banana fruits. Determination of SSC for banana often requires destructive laboratory analysis on the fruit. An impedance measurement technique was investigated as a non-destructive approach for SSC determination of bananas. A pair of electrocardiogram (ECG) electrode connected to an impedance analyser board was used to measure the impedance value of bananas over the frequency of 19.5 to 20.5 KHz. The SSC measurement was conducted using a pocket refractometer and data was analysed to correlate SSC with impedance values. It was found that the mean of impedance, Z decreased from 10.01 to 99.93 KΩ at the frequency of 20 KHz, while the mean value of SSC increased from 0.58 to 4.93 % Brix from day 1 to day 8. The best correlation between impedance and SSC was found at 20 KHz, with the coefficient of determination, R^2 of 0.87. This result indicates the potential of impedance measurement in predicting SSC of banana fruits.

Keywords: Banana ripeness, impedance measurement, non-destructive, soluble solid content (SSC)

INTRODUCTION

Banana *(Musa paradisiaca L.)* is the most preferred fruit for healthy eating diet. A finger of a banana provides 23% of the potassium that we need on a daily basis and it also provides an excellent source of vitamin A, B6, C and D (Kumar et al., 2012). The nutritional values of bananas vary between degrees of ripeness. Bananas also rich in carbohydrates and in unripe stage, bananas mostly starches. The starches converted into sugar during ripening, a fully ripe banana has only 1-2% starch (Forsyth, 1980).

In the post-harvest production, banana is cut at the mature-green stage to preserve a firm pulp texture, good colour and flavour (Soltani et al., 2010) and then the fruit is artificially ripened under ethylene treatment. In this case, quality assessment is important to make sure that the bananas are ready to

be marketed or exported. Soluble solid content (SSC) is often used as a quality indicator for bananas. Usually, SSC of banana is increased as it reaches the ripening stage. Traditionally, determination of SSC requires a flesh of banana fruit for destructive measurement using refractometer (Harker et al., 2002). The destructive test is not practical for quality assessment because it will cause damage to the fruit.

Therefore, many studies were done to replace the destructive test in SSC determination. Several non-destructive methods to assess the quality of bananas optical chlorophyll sensing system (Li et al., 1997), neural network-based electronic nose (Llobet et al., 1999) and near infrared (NIR) spectroscopy (Liew & Lau, 2012). Li et al. (1997) studied the use of optical chlorophyll sensing system to measure the chlorophyll content of banana peels and the results showed a high correlation to other peel colour analysis such as spectral analysis. However, this sensing system is not reliable for predicting peel colour changes of banana at the ripeness stage above four. Llobet et al. (1999) reported that fuzzy-adaptive resonance theory mapping (ARTMAP) based electronic nose provides an attractive means for classifying the ripeness of bananas. This system was able to predict the state of ripeness of unknown sets of bananas with 90% accuracy. Liew and Lau (2012) used NIR spectroscopy combined with multiple linear regression (MLR) to determine the ripeness stage of Cavendish bananas and found that NIR had the potential for non-destructive determination of internal quality of Cavendish bananas such as SSC and firmness.

In addition, some researchers proposed the use of nuclear magnetic resonance (NMR) and proton magnetic resonance (PMR) as non-destructive methods to determine levels of soluble solid (Cho et al., 1990; Wai et al., 1995). However, all the studies are only fundamental approaches that are far from reaching the practical application and some of the techniques, like NMR and PMR, rely upon expensive equipment and required skilled operators.

Since 1980's, dielectric properties measurement of several fruits and vegetables have been studied as a non-destructive approach. Nelson (1980) measured dielectric properties of peaches at microwave frequency and found that no differences in dielectric properties at 2450 MHz were distinguishable between mature green and full-ripe peaches. Then, permittivity-based maturity indices of peaches, which combine the dielectric constant values at 200 MHz and the loss factor values at 10 GHz, were suggested; however, a lot more work is required to establish their practicality (Nelson et al., 1995). A linear relationship complex-plane plot for permittivity components divided by SSC for external surface measurements at 40 MHz and 24°C was found on watermelon (Nelson et al., 2007). However, it is not useful in predicting SSC values from the dielectric properties because of the poor relationship between SSC and the dielectric properties of R^2 of 0.4.

Another study on the feasibility of capacitance measurement for under ripe and ripe banana was carried out using parallel plate capacitor at different plate separation by Zulhusin et al. (2008). They found that the difference between maturity levels depends on the plate separation and the best separation of the plate was found at 4 cm. Later, Soltani et al. (2010)also investigated the capacitive property of banana fruits by using parallel plate capacitor and they found that permittivity for green-ripe and full-ripe banana was changed from 1.74 to 1.64, respectively, at 1 MHz. Linear regression at 1 MHz for both SSC and firmness with relative permittivity provides an acceptable correlation in predicting banana quality during the ripening treatment.

In recent decades, electrical impedance measurement has been broadly used to study the electrical properties of plant tissue (Zywica et al., 2005; Liu, 2006; Fang et al., 2007). Electrical Impedance Spectroscopy (EIS) is suitable for non-destructive techniques which provide easy, inexpensive and rapid assessment (Bauchot et al., 2000; Zywica et al., 2005; Juansah et al., 2012; Caravia et al., 2015). Electrical impedance measurement has been used in quality assessment of agriculture produce to determine the soluble solid content of fruits (Zywica et al., 2005; Fang et al., 2007; Guo et al., 2011), or evaluate the bruising damage in fruits, assess the moisture and salt content in smoked fish (Karásková et al., 2011), evaluate the quality of meat (Freywald et al., 1995) and determine the freshness of fish and shrimp (Marshall & Wiese-Lehigh, 1997; Niu & Lee, 2000).

Therefore, this study aims to use impedance spectroscopy technique as a potential measurement method in assessing SSC of bananas. The objectives of this study are to investigate the electrical impedance of banana from *Berangan* variety during ripening and to find the correlation between impedance and SSC measurement.

MATERIAL AND METHODS

Banana samples preparation

Six hands of green bananas, *Musa paradisiaca L.*, from *Berangan* variety were purchased from a local market at ripening stage one with approximately 15 or 20 fingers in each hand. The bananas were cleaned with tap water to remove any foreign material from its skin and dried by using tissues. After that, they were kept in a box at a room temperature of 26°C for eight days. Each day, four fingers of bananas were taken randomly from the box and their impedance and SSC were measured. A total of 32 fingers of banana (4 fingers of banana x 8 days = 32 fingers) were used for impedance and SSC measurements.

Impedance measurement

The impedance measurement was carried out using a pair of electrocardiogram (ECG) electrodes which were connected to an impedance analyser board, AD5933 (Analog Devices Inc., MA, USA) and a computer. The ECG electrodes were composed of a small metal plate surrounded by an adhesive pad, which was coated with conducting gel to help transmit electrical signal (Figure 1). Impedance measurement was obtained along a sweep frequency from 19.5 to 20.5 KHz. The magnitude and phase of the impedance at each frequency point along the sweep were calculated. The range of sweep frequency from 19.5 to 20.5 KHz was chosen after several trials were done and this sweep frequency was found to provide sensitive reading to distinguish the level of SSC content in banana fruit. The impedance converter system was connected to a computer and data were acquired using AD5933 evaluation software (Analogue Devices Inc., MA, USA). The ECG electrodes were discarded after each measurement. The measurements were conducted at a room temperature of 26°C. After completion of the impedance measurements, the SSC measurements were performed.
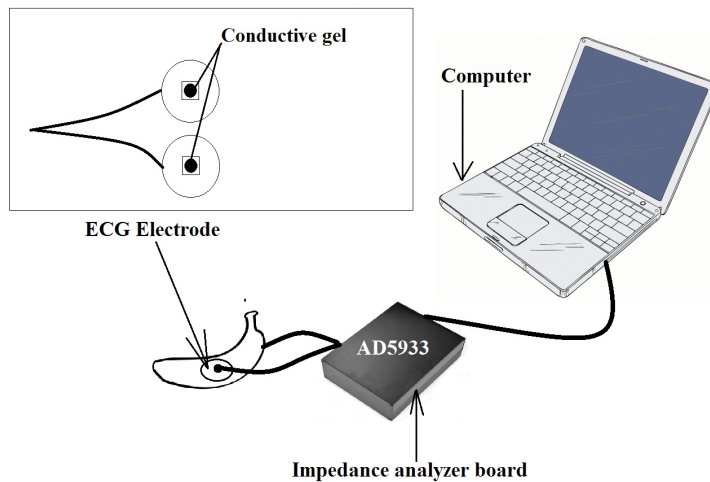
Figure 1. Experimental set-up for impedance measurement

SSC measurement

SSC value of each finger of banana was determined from its juice. For each banana finger, the juice was expressed from 10 g of banana flesh using a blender. The flesh was blended with 40 ml distilled water for one minute until sufficiently homogenised and then the juice was collected in a 50 ml beaker. The SSC was measured with a Pocket Refractometer PAL-α (Atago Co., Ltd, Tokyo, Japan) by placing a drop of the juice on the prism glass. The refractometer readings are referred to as Brix readings, which expressed in percent total solids by weight (Harker et al., 2002). Three replicate of SSC readings were recorded for each finger of banana.

Statistical analysis

Relationships between impedance and SSC were analysed using Analysis ToolPak option in Microsoft Excel 2007 (MS Corporation, Redmond, WA, USA). Significant differences of impedance and SSC during eight days of measurement were determined using analysis of variance (ANOVA) and mean separation by Duncan Multiple Range Test (DMRT) at the 5% probability level. This analysis was performed using SAS 9.1 (SAS Institute, Inc., Cary, NC, USA).

RESULTS AND DISCUSSIONS

The mean of impedance and SSC values over the eight days of measurement were shown in Table 3. The SSC values were found to increase steadily day by day. This increment had been expected as SSC usually increases as the banana ripens due to the conversion of starch to soluble sugar. The increase of SSC is an important trait of hydrolysis of starch into soluble sugars such as glucose, sucrose and fructose (Marriot et al., 1981). For impedance, a decrease occurred with the most frequency. Results indicated that impedance decreased when SSC increased during ripening.

Changes in impedance and SSC value during ripening

ANOVA showed that there were highly significant differences found between impedance and SSC during ripening with α level less than 0.0001 (Table 1 and Table 2). To further investigate the differences, mean separation by DMRT was performed. The mean value of SSC and impedance data at five frequencies (19.5, 19.9, 20, 20.1 and 20.5 KHz) over eight ripening days were summarised in Table 3. Based on the results in Table 3, there was a significant difference found in SSC during ripening, except for day 1 and day 2. The mean of SSC increased from 0.58% Brix to 4.93% Brix. The results also clearly indicated that from day 1 to day 8 a decrement trend was found in the mean of impedance from 10.01 to 99.93 KΩ at 20 KHz (Table 3). However, between day 5 and day 6, as well as for day 7 and day 8, there was no significant difference in the mean of impedance (Table 3).

Table 1

ANOVA for impedance measurement

Source of Variation	F	p-value	
Day	21.18	<.0001	***

Note. *** Highly significant difference in the means of impedance during ripening.

Table 2

ANOVA for SSC measurement

Source of Variation	F	p-value	
Day	194.27	<.0001	***

Note. *** Highly significant difference in the means of impedance during ripening.

Table 3

Impedance and SSC measurements over the frequency range from 19.5 to 20.5 KHZ during eight days

Day	SSC (%Brix)	Frequency (KHz)				
		19.5	19.9	20	20.1	20.5
1	0.58 a*	10017.80 a	10012.98 a	10011.88 a	10008.03 a	10001.38 a
2	0.78 a	10021.13 a	10010.43 a	10010.20 b	10008.24 a	10000.11 a
3	1.70 b	10015.10 a	10008.39 b	10006.77 c	10003.78 b	9997.56 a
4	2.15 c	10016.84 a	10009.20 b	10005.62 d	10005.33 a	9996.66 a
5	3.05 d	10015.42 a	10006.66 c	10001.67 e	10004.25 b	9997.85 a
6	3.69 e	10015.10 a	10006.33 c	10001.16 e	10004.58 b	9997.19 a
7	4.42 f	10010.07 b	10004.29 d	9996.06 f	10002.59 c	9997.16 a
8	4.93 g	10003.50 c	10001.38 d	9993.98 f	9999.13 c	9997.72 a

Note. *Means within a column followed by a common letter are not significantly different at the 5% probability level

Correlation between impedance and SSC measurement

The conversion of starch during ripening process usually increases the content of soluble sugar in banana. The increase of sugar content in fruit pulp with the loss of water from fruit during ripening enhances the concentration of ions (Liu, 2006). High concentration of ions in the electrolyte of banana leads to the low value of impedance (Zywica et al., 2005). As discussed earlier, SSC was found to have increased while impedance decreased during ripening. Their correlation was investigated using linear regression. The result from linear regression showed that SSC exhibited negative linear correlation with impedance (Figure 2) with the highest R^2 found at the frequency of 20 KHz (Table 4). This result is similar to the result reported by Fang et al. (2007), where SSC has linear correlation with impedance in predicting the quality of apple from a different variety. The relationship can be expressed in the regression equation, as follows:

$$SSC = -0.22 \ Z + 2224.48 \tag{1}$$

where Z is the impedance in ohm (Ω). This equation can be used to predict SSC from impedance measurements.
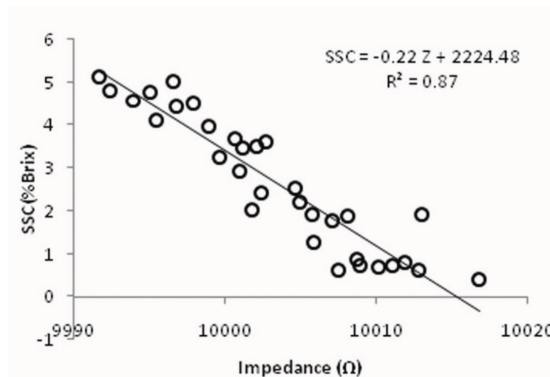

Figure 2. Relationship between impedance and SSC value of bananas at 20 KHz

Table 4

Linear regression equation to predict the SSC of banana fruits using impedance value

Regression equation	R^2	Frequency (KHz)
SSC = -0.20 Z+ 2035.90	0.63	19.5
SSC = -0.30 Z+ 3008.50	0.67	19.9
SSC = -0.22 Z+ 2224.48	0.87	20
SSC = -0.27 Z+ 2700.30	0.46	20.1
SSC = -0.17 Z+ 1739.10	0.13	20.5

CONCLUSION

Measurement of impedance on 32 fingers of banana during eight ripening days provided useful information in developing a non-destructive method for quality assessment of banana. The impedance values from the measurements decreased when the SSC increased from day 1 to day 8. A negative linear relationship was found between impedance and SSC, with $R^2 = 0.87$ at 20 KHz. The correlation between impedance and SSC showed good potential in developing a non-destructive method for SSC determination and online quality sensing. Further research is needed to validate the reliability of the equation.

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