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Minimally destructive assessment of mangosteen translucency based on electrical impedance measurements

Natrapee Nakawajana [a], Anupun Terdwongworakul [a, *], Sontisuk Teerachaichayut [b]

[a] Department of Agricultural Engineering, Faculty of Engineering at Kamphaengsaen, Kasetsart University, Kamphaengsaen, Nakhon Pathom, Thailand
[b] Department of Food Process Engineering, Faculty of Agro-Industry, King Mongkut's Institute of Technology Ladkrabang, Chalongkrung Road, Ladkrabang, Bangkok 10520, Thailand

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ABSTRACT

Electrical impedance spectroscopy in a frequency range of 1 kHz–200 kHz was studied to develop a classifying model for translucent mangosteen. The optimal configuration of the measurement was investigated. Transverse alignment of two measuring needles with the stem–calyx axis and with the measured position on the part of the pericarp pertinent to the largest flesh segment proved to be the optimal configuration. The optimal electrical parameters were selected at frequencies of 1, 4, 7, 8, 14, 47, 73, and 81 kHz as the classifying variables based on the student *t*-test analysis for a significant difference between the normal and translucent mangosteen and the largest difference of the average values of the electrical parameters. The differences in the electrical parameters and their reciprocals were the optimal classifying variables. The model constructed from the samples from two seasons was robust in terms of seasonality, providing a classification accuracy of 82.7%. The difference in the initial moisture content of the pericarp was justifiably compensated by the differences in the electrical parameters. The EIS technique was suitable for measurement of mangosteen samples at the maturity color stage in which the sample contained no yellow latex in the pericarp.

1. Introduction

The quality of the mangosteen (*Garcinia mangostana* L.) fruit is ascertained by observing not only external factors including color, shape, size, skin blemishes, latex staining, and insect damage but also internal factors such as translucency of the flesh, the yellow gummy latex, and the hardening pericarp. These factors appreciably influence consumer acceptance. Flesh translucency disorder is a particularly undesirable feature with regard to the quality of mangosteens expected for export.

A number of techniques were researched to predict disorders in mangosteens. X-ray NMR imaging and CT were applied to detect the translucent flesh of mangosteens (Yantarasri et al., 1998). Flesh translucent disorder was found to be related to moisture and was evaluated using a microwave technique with an overall accuracy of 79% (Tongleam et al., 2004). A floating technique that exploits the variation in specific gravity is usually used as a non-destructive method for detecting translucent flesh in mangosteens; however, the obtained results are not reliably accurate. For export purposes, each individual mangosteen fruit has its pericarp partially cut open to allow visual inspection of the fruit to check for the appearance of translucency. A fruit without visible translucency has its pericarp closed, is subsequently taped around the cut line, and is frozen for export. Near-infrared spectroscopy based on transmittance was investigated and shown to successfully identify the translucent mangosteens with a classification accuracy of 92% (Teerachaichayut et al., 2007). However, the resulting NIRS-based machine for inspecting fruit in mass quantities, was expensive, which makes this an unsuitable solution for small- and medium-sized businesses.

Electrical impedance spectroscopy (EIS) has been an interesting technique for *in vivo* assessment of the condition of plant tissues. The advantage of EIS is its capacity for easily and rapidly performing measurements. There have been many studies of the use of EIS on agricultural products. For example, the extent of tissue damage associated with apple bruises was successfully evaluated (Jackson and Harker, 2000). EIS was also used as a technique to determine the ripening of fruit (Harker and Dunlop, 1994; Harker and

* Corresponding author.
E-mail addresses: fengant@ku.ac.th, anupunterd@yahoo.com (A. Terdwongworakul).

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Maindonald, 1994). For nectarines, for instance, a reduction in the resistance of the apoplast was discerned immediately after harvest (Harker and Maindonald, 1994). A non-destructive impedance-spectroscopy technique was preliminarily investigated for future development of a robotic harvesting arm for mangos (Rehman et al., 2011). Impedance spectrometry was shown to be capable of characterizing raw and ripe mangos in the frequency range of 1–200 kHz. EIS was also proposed for use in the official control laboratories for determination of the floral origin of honey due to the rapidity and ease with which measurements could be made with no sample preparation (Scandurra et al., 2013).

Translucent mangosteen has significantly higher water content in pericarp and flesh than normal fleshy fruits (Pankasemsuk et al., 1996). As the moisture content in a plant is related to the plant's electrical properties, EIS could act as a possible technique for assessing the water content in the pericarp in association with the translucency in mangosteen. To date, there have been no studies on the application of EIS to the evaluation of mangosteen translucency. The work we describe here reports on the application of EIS to the classification of translucent mangosteens. The optimal measurement configurations for the impedance parameters derived from the EIS of the pericarp were explored.

2. Materials and methods

In the 2014 season, a sample set of 143 mangosteen fruits with maturities at color stage 5 when the fruit skin color was dark purple (Palapol et al., 2009) (which was a color suitable for sale at local markets) was purchased from a wholesale market. Samples in the 2015 season were obtained at color stage 4 (red to reddish-purple) suitable for export, and stage 5 (Tongdee and Suwanagul, 1989; Palapol et al., 2009) accounting for 104 and 75 fruits, respectively. The sample fruits were then transported in an air-conditioned truck to the laboratory and kept at 25 °C and a relative humidity of approximately 85% in an air-conditioned laboratory overnight so as to attain temperature equilibrium prior to measurement.

2.1. Measurement of electrical impedance spectroscopy

EIS measurements were performed using an LCR meter (3532-50, Hioki E. E. Corporation, Nagano, Japan) in a frequency range of 1 kHz–200 kHz using frequency steps of 1 kHz and a measuring voltage of 1 V. A four-terminal probe (9140-10, Hioki E. E. Corporation, Nagano, Japan) was used to minimize electrode polarization impedance. The change in electrical impedance was measured between two silver needles inserted with a penetration depth of 4 mm and spaced 5 mm apart on the middle part of the pericarp of the whole fruit. The reactance (X), resistance (R), capacitance (C), and impedance (Z) as functions of frequency were recorded and transferred to a computer for further analysis by the Hioki LCR-RS232C V4.01e software package (Nagano, Japan).

To examine the effect of using a particular measurement position, the EIS scans were performed at eight positions located at intervals of 45° along the circumference of the equator of each sample (Fig. 1). Visual inspection (Fig. 2) on the internal pericarp of the cut-open mangosteens revealed that the largest segment of the flesh is normally translucent (Chaisrichonlathan and Noomhorm, 2011). Therefore, the first position of the measurement is referenced at the external surface of the pericarp where the internal segment has its largest external surface area (Terdwongworakul et al., 2012). The largest internal segment was identified by the assessment of the external shape of the fruit. The number of petals on the bottom of the mangosteen can be used to indicate the number of flesh segments within the fruit. Thus, the first position on the fruit was visually assigned by means of assessment of the eccentric shape and the petal direction on the bottom of the fruit (Terdwongworakul et al., 2012). The second position was located 45° counterclockwise from the first position when viewed from the stem (Fig. 2). The subsequent positions were referenced in proximity to the previous positions in an analogous manner. In addition, the effect of the alignment of the measuring needles was also investigated. At each of the eight positions used for the measurements, two samples were taken with two needles either aligned along the stem–calyx axis (A) or perpendicular to the stem–calyx axis (P) (Fig. 1). Thus, a normal mangosteen and a translucent mangosteen measured with the needles aligned along the stem–calyx axis were designated "NA" and "TA" respectively.

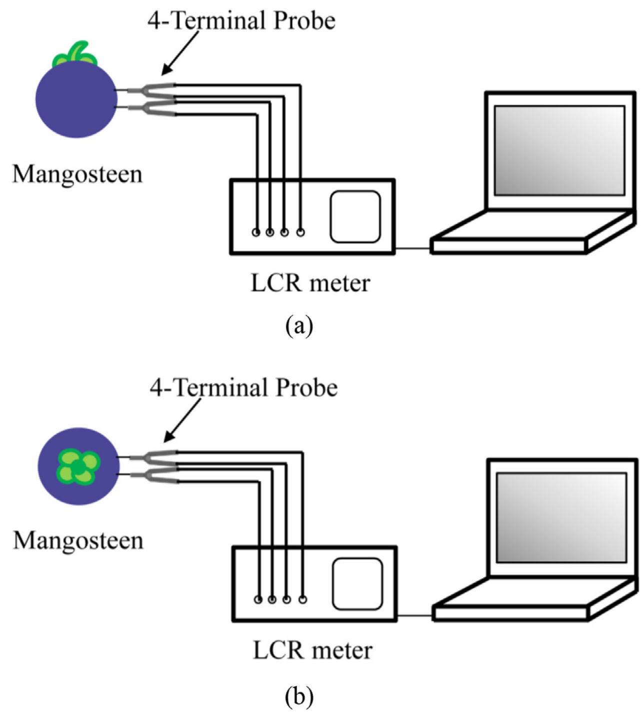

Fig. 1. Layout of the instrument for measurement of the electrical impedance on the mangosteen sample with two orientations: (a) one with the needles aligned along the stem–calyx axis, which we designate as orientation "A" and (b) one with the needles perpendicular to the stem–calyx axis, denoted "P."

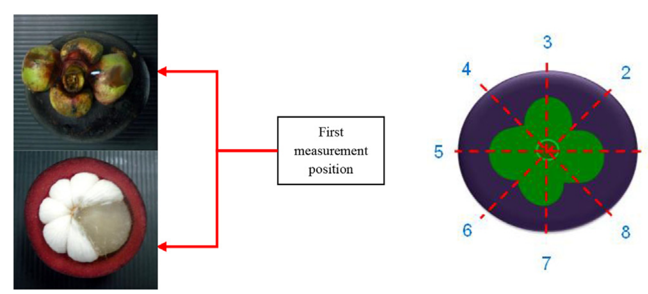

Fig. 2. Depiction of the first measurement point for the EIS scan, corresponding with the largest segment (which causes the eccentric shape of the fruit). The second position was located 45° counterclockwise from the first position.

2.2. Determination of moisture content of the pericarp

The pericarps of mangosteens at eight positions on the circumference of the equator of each sample were determined for the moisture content. A sample of about 10 g of the pericarp was