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Quality evaluation of watermelon using laser-induced backscattering imaging during storage

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ABSTRACT

Non-destructive and optical-based technologies are rapidly being engaged as alternative techniques for monitoring quality changes in agricultural produce. In the present work, the feasibility of laser-induced backscattering imaging was investigated to predict the changes of firmness, soluble solids content (SSC), pH, and moisture of watermelon during storage. Backscattering images were obtained from Black Beauty and Red Seedless watermelons using a laser diode emitting at the wavelength of 658 nm. Different multivariate methods were evaluated on the backscattering parameters (BP) for monitoring the quality changes of watermelons at different storage days. A partial least squares (PLS) regression was applied to the BP extracted from the backscattering images to analyze the quality attributes of the two watermelon cultivars. Among all of the quality changes, the moisture prediction gave the highest coefficient of determination (R^2) of 0.942 and root mean square error of prediction (RMSEP) of 0.492, respectively. Therefore, this study has demonstrated the capability of laser-induced backscattering imaging as a useful, rapid, and non-invasive optical technique for the evaluation of the quality of watermelons during storage.

1. Introduction

Watermelon is one of the tropical fruits which is often favored among all of the different types of fresh agricultural produce worldwide. For the commercial market, fresh and high-quality watermelons are harvested at a suitable maturity level based on the appearance of the fruit. With respect to this condition, the internal quality is required for monitoring the quality changes especially during storage. Physicochemical and environmental aspects are the main factors that could affect the quality of the fruit with regard to texture, sweetness, flavor, color, and shelf-life (Wani et al., 2014). Apart from that, the evaluation of fruit quality is crucial to determine the consumer's choice when purchasing fresh watermelon, taking into account the quality grade and fruit maturity.

Recently, non-destructive optical techniques have been used in the evaluation of quality for various types of food and agricultural produce during postharvest processing. In this regard, numerous non-destructive techniques have been applied due to the robustness of the device, the lack of need for sample preparation, and the ability to perform rapid measurements (Aftab et al., 2011; Ignat et al., 2012; Jha and Matsuoka, 2000; Jha et al., 2011; Romano et al., 2011; Sun et al., 2010). For instance, near-infrared (NIR) spectroscopy is used to predict the quality attributes of horticultural produce in the wavelength region from 700 nm to 2500 nm (Ignat et al., 2012; Jha et al., 2014; Louw and Theron, 2010; Sankaran et al., 2011; Wu et al., 2016; Xie et al., 2011). However, NIR spectroscopy does not deliver computable information regarding the influence of light scattering from the tissue of the fruit. Therefore, an alternative technique has been explored and rapidly applied to retrieve quantitative information based on the propagation of light scattering.

In postharvest technology, laser-induced backscattering imaging is offered as one of the promising techniques that integrate image processing and computer vision applications. In particular, the backscattering profile is very much related to the absorption and scattering properties of the fruit. Light absorption is associated to the chemical constituents in the fruit, whereas light scattering is related to the mechanical and physiological properties of the fruit tissue (Lu, 2004). Mollazade et al. (2012) reported that the absorption property provides information on the quality attributes within the fruit tissue, whereas the scattering property is based on the inter-cellular information in the cell structure.

The main component in the implementation of laser-induced backscattering imaging is the laser diode which acts as a light

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source in the system. Laser diodes are comparatively easy to mount on the imaging unit as they are durable, a capable light propagation device, and are proficient for penetration into the fruit tissue (Romano et al., 2011). The laser diode is also favorable due to the improvements of auto-calibration and integration with a computer-aided system. In the laser-induced backscattering imaging system, the size and the incident angle of the laser beam are the two main factors in selecting the light source. The smaller laser beam size is preferable due to the ability of the scattered light to produce better region area (Mollazade et al., 2012). It is quite challenging to find the appropriate size and incident angle of the laser beam since the selection criteria are also dependent on the surface area of the agricultural produce. The recommended incident angle of the laser beam is between 7° and 25° with the reference to the vertical axes (Lu, 2004). Previous studies have also indicated the use of beam size, such as the beam size of 4.5 mm (Romano et al., 2008), 2.5 mm (Udomkun et al., 2014), 1 mm (Hashim et al., 2014; Mollazade et al., 2013), and 1.5 mm (Qing et al., 2007). One of the benefits of the small laser beam is the symmetry of the backscattering images to the incident angle is perpendicular to the surface of the sample, which makes the pre-processing of the images much easier (Mollazade et al., 2012). Moreover, a laser diode requires less power supply besides providing the adequate value of light intensity on the surface of the fruit. The backscattering image encompasses the highest light intensity at the center and deviates along the radial axis of the fruit surface (Lorente et al., 2015; Mollazade et al., 2012). The intensity values reduced across the radial axis depending on the physical and physicochemical properties of the produce.

Previous research studies have highlighted the feasibility of laser-induced backscattering imaging in monitoring food quality in various agricultural produce including bananas (Hashim et al., 2014, 2013, 2012), kiwifruits (Baranyai and Zude, 2009), citrus fruits (Lorente et al., 2015, 2013), papayas (Udomkun et al., 2014), and apples (Qing et al., 2007; Romano et al., 2011). Hashim et al. (2013) investigated chilling injury and the relationship between water content and BP in bananas at 660 and 785 nm wavelength bands based on visual inspection and the storage period. Udomkun et al. (2014) studied the influence of drying temperatures with quality parameters (moisture content, shrinkage, and color changes) of papayas during drying emitting at three different wavelengths (532, 650, 780 nm). Lorente et al. (2015) reported the feasibility of laser-induced backscattering imaging to evaluate the measurement of the optical properties of decayed citrus fruit at five different wavelengths (532, 660, 785, 830, 1060 nm) over the decaying process of the fruit. Romano et al. (2012) analyzed the color changes and moisture content of bell peppers emitting at wavelengths (532 and 635 nm) during drying, with regard to the changes of the scattering properties of the fruit. However, the understanding of this technique is still limited for exploring quality attributes in tropical fruit such as watermelon. Thus, the main objective of the present study was to investigate the application of backscattering imaging techniques to evaluate the quality changes of watermelon during storage. The application of partial least squares (PLS) regression analysis for data processing was investigated.

2. Materials and methods

2.1. Sample preparation

Fresh watermelons, '*Black Beauty*' and '*Red Seedless*' were procured from a local farm in Perak, Malaysia at the end of November 2015. The fruits were stored under optimized conditions, i.e. 10 °C and 85 % relative humidity before the measurements were taken. A total of 70 fresh watermelons with 35 samples per each variety were measured in this study. The measurement was conducted on five watermelons from each variety at seven storage days (0, 4, 8, 12, 15, 18, and 21 d) for three weeks of the storage period.

2.2. Laser-induced backscattering imaging system

Backscattering images of watermelons were acquired using a laser-induced backscattering imaging system developed in the Department of Biological and Agricultural Engineering, Faculty of Engineering, Universiti Putra Malaysia, Malaysia. The developed system mainly consists of a charge-coupled device (CCD) camera (QICAM Color Fast 1394, QImaging, Surrey, BC, Canada) with a zoom lens (F5.6 and focal length of 18 mm), a laser diode emitting at 658 nm with 30 mW maximal power, and Image-Pro Insight 9 software (Media Cybernetics, Inc., USA) to obtain the backscattering images. The backscattering images (1392 × 1040 pixels) by 12 bits were obtained using a laser diode of 1 mm diameter, providing an intense light intensity into the fruit tissue. The incident angle of the light beam was positioned at 22° whereas the distance between the camera and the fruit samples was set at 55 cm from the datum surface. A frame covered with black cloth was used to minimize light interruptions from the surroundings. Each watermelon was placed manually in such a way that the laser diode was aimed at the top surface of the fruit. Six images were acquired per fruit with an overall of 70 samples, producing a total of 420 backscattering images.

2.3. Determination of physicochemical properties

The physicochemical properties of the watermelons (soluble solids content, pH, firmness, and moisture content) were measured using conventional destructive methods. The firmness of the watermelon flesh was determined using a 3.5 mm diameter plunger tip, attached to a handheld penetrometer (GY-1, G-tech Co. Ltd., China). The maximum force was obtained by pushing the plunger tip into the fruit flesh. Then, the juice was extracted for soluble solids content (SSC) and pH measurements. The SSC measurement was measured by a handheld digital refractometer (Pal-1, Atago Co., Tokyo, Japan) while pH was determined using a digital pH meter (DPH-2, Atago Co., Tokyo, Japan). The moisture was determined using an air oven method according to the Association of Official Analytical Chemists (AOAC International) standard (Horwitz, 2000). The watermelon flesh was diced into cubes with a standard size of 2 cm × 2 cm × 2 cm and this was repeated in three replications for all fruit samples. All of the physicochemical properties were measured at the same locations of the fruit in which the image acquisition had just been performed.

2.4. Backscattering image analysis

Image segmentation involves the separation of the region of interest (ROI) from the background of the image. The image segmentation process was carried out using Matlab software (Version R2013a, The Mathworks Inc., Natick, MA, USA) based on the feature extraction, which is retrieved from the backscattering images. The image segmentation process was carried out to remove saturated pixels in the image. The region of saturated pixels based on the image was segmented using a thresholding method alongside morphological dilation and erosion operations. Since the segmented region comprised of the backscattering photons, image thresholding was done to eliminate uneven illumination from the background of the backscattering image (Mollazade et al., 2013). Based on the pixel image, the threshold value was selected from the neighborhood pixels. The selection of