Computers and Electronics in Agriculture 140 (2017) 311–316

Contents lists available at ScienceDirect

Computers and Electronics in Agriculture

journal homepage: www.elsevier.com/locate/compag

Original papers

Laser-induced backscattering imaging for classification of seeded and seedless watermelons

Maimunah Mohd Ali [a], Norhashila Hashim [a,*], Siti Khairunniza Bejo [a], Rosnah Shamsudin [b]

[a] Department of Biological and Agricultural Engineering, Faculty of Engineering, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia
[b] Department of Food and Process Engineering, Faculty of Engineering, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia

ARTICLE INFO

Article history:
Received 27 October 2016
Received in revised form 20 April 2017
Accepted 10 June 2017
Available online 20 June 2017

Keywords:
Backscattering imaging
Laser light
Watermelon
Pattern recognition algorithm
Storage

ABSTRACT

This paper evaluates the feasibility of laser-induced backscattering imaging for the classification of seeded and seedless watermelons during storage. Backscattering images were obtained from seeded and seedless watermelon samples through a laser diode emitting at 658 nm using a backscattering imaging system developed for the purpose. The pre-processed datasets extracted from the backscattering images were analysed using principal component analysis (PCA). The datasets were separated into training (75%) and testing (25%) datasets as the inputs in the classification algorithms. Three multivariate pattern recognition algorithms were used including linear discriminant analysis (LDA), quadratic discriminant analysis (QDA), and k-nearest neighbour (kNN). The QDA-based algorithms obtained the highest overall average classification accuracies (100%) for both the seeded and seedless watermelons. The LDA and kNN-based algorithms also obtained quite high classification accuracies with all the accuracies above 90%. The laser-induced backscattering imaging technique is potentially useful for classification of seeded and seedless watermelons.

1. Introduction

Watermelon (*Citrullus lanatus*) is an edible and beneficial fruit which is available all year round in Malaysia (Mohd Ali et al., 2017). The fruit is the world's second most famous fruit with approximately 109.28 million metric tons global production in 2013 (FAO, 2015). Watermelon is well-known for its sweet and juicy flesh. The fruit is denoted as a pepo, which is a special type of berry that has a thick rind and deep flesh inside (Ajuru and Okoli, 2013). The pepo is also developed from the inferior fruit which is distinctive for the watermelon crop. Normally, the colour of the internal watermelon flesh of most commercial cultivars is red or yellow, while the watermelon rind colour varies from light to dark green with yellow spots, stripes or marbling. As an added value, the entire fruit is edible and is frequently eaten raw or consumed as a juice, stir-fried, in a salad, or pickled.

Apart from the above, watermelon differs in terms of shape and size from circular to oblong. The fruit has a high water content and is a good source of vitamins and minerals such as carbohydrates, calcium, phosphorus, and ascorbic acid (Tlili et al., 2011). Watermelon is also proven to be a source of lycopene and citrulline (Perkins-Veazie and Collins, 2004; Rimando and Perkins-Veazie, 2005). Citrulline is a non-essential amino acid obtained from the watermelon juice whereas lycopene is a type of carotenoid that gives the distinct property of a red colour (Liu et al., 2010). In addition, watermelon is a non-climacteric fruit which does not undergo a continuous process to ripen after being harvested (Wechter et al., 2008). The fruit belongs to the family of *Cucurbitaceae* that consists of numerous cultivars, including seeded, seedless and disorder-resistant varieties (Perkins-Veazie et al., 2006).

Technically, since the seedless watermelon cannot be planted through seed germination, the fruit has to be cultivated by using different scientific methods. The seeded watermelon is normally pollinated using pollen, whereas the seedless watermelon is produced from a hybrid watermelon which consists of three sets of chromosomes in terms of a genetically-engineered procedure (Griffiths et al., 1999). However, as farmers start to plant seedless cultivars, roughly one-third of the crops are left to plant seeded watermelons for sufficient pollination and yield production. Watermelon cultivars also like dry conditions, especially with exposure to sunlight and temperature during the growing period.

There are several criteria to be considered when choosing a variety of watermelon. The main characteristics are colour and visual inspection of the fruit (Zhang et al., 2014). The harvesting process is much easier for the seedless cultivar due to the different colour compared to the pollination of the seeded variety. Size is

* Corresponding author.
E-mail address: norhashila@upm.edu.my (N. Hashim).

http://dx.doi.org/10.1016/j.compag.2017.06.010
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also one of the criteria as the shape and size vary between both varieties (Zheng et al., 2006). Conversely, seedless watermelon is grown to have immature seed which is developed from the triploid trait and comprises of numerous large seeds throughout the flesh of the hybrid watermelon. For this reason, the seedless variety is more valuable in commercial markets due to the preference and convenience requirements of the customers.

Recently, laser-induced backscattering imaging has been applied for non-destructively evaluating various agricultural produce in terms of food quality and control as an alternative to the machine vision method. Previous works have discussed the feasibility of laser-induced backscattering imaging in evaluating the food quality of fruits and vegetables such as apples (Qing et al., 2007; Romano et al., 2011), bell peppers (Romano et al., 2012), tomatoes (Mollazade et al., 2013; Tu et al., 2000), bananas (Adebayo et al., 2016b; Hashim et al., 2014, 2013, 2012), kiwifruits (Baranyai and Zude, 2009), citrus (Lorente et al., 2015; Lorente et al., 2013), and papayas (Udomkun et al., 2014). Romano et al. (2011) applied laser light backscattering imaging emitted in the visible wavelength at 635 nm to determine moisture content, soluble solids content, and hardness of apples during drying. Lorente et al. (2013) used a laser diode emitting at five different wavelengths (532, 660, 785, 830, and 1060 nm) to detect decay in citrus fruits in comparison with respective laser wavelengths. In previous research, Hashim et al. (2013) investigated the effect of water content, fruit pigment, and chilling injury in bananas with respect to storage time and temperature using laser-induced backscattering imaging. Dénes et al. (2013) reported the application of a backscattering imaging system on the optical properties of bananas based on the influence of different drying times, temperatures, and pre-treatments emitting at seven wavelengths (532, 635, 650, 780, 808, 850, and 1064 nm). Qing et al. (2008) analysed backscattering images of apples to determine the firmness and soluble solids content in different growing locations.

Basically, laser induced backscattering imaging uses the theory of light propagation when the light is reflected and scattered back towards the external surface of the sample upon entering the fruit tissue. In this case, the backscattering photons obtained through light propagation carry useful information associated with the morphology properties of the flesh when interacting with the quality attributes of the fruit sample (Adebayo et al., 2016a; Mollazade et al., 2012). Moreover, the methods developed for processing the backscattering images are computationally inexpensive. The low processing cost suggests that a laser-based system could possibly be developed and applied, especially in real-time sorting/grading machines. However, as far as is known, no study has reported a technique able to classify seeded and seedless watermelons coupled with classifier models using a laser-induced backscattering imaging system. Thus, the ultimate aim of this study is to evaluate the application of laser-induced backscattering imaging for the classification of seeded and seedless watermelons during storage. This study also investigates different pattern recognition algorithm models for the classification of seeded and seedless watermelons.

2. Materials and methods

2.1. Sample preparation

Seeded watermelons from the Black Beauty variety and seedless watermelons from the Red Seedless variety were procured from a local farm in Manjung, Perak, a middle state in Malaysia. The watermelons were harvested 65 days after planting and delivered to a commercial retailer (Melon Master Sdn. Bhd.). The fruits were transported immediately to the Biomaterials Processing Laboratory, Universiti Putra Malaysia and stored in cold storage (12 °C and 80–90% RH). The experiments were carried out in two batches for three weeks in order to identify the similarity and differentiation throughout the storage period. For each cultivar, 70 Black Beauty and Red Seedless watermelons were measured with a total of 140 watermelons for each batch, respectively. Seven interval storage days were used to analyse the physicochemical changes of both varieties (day 0, day 4, day 8, day 12, day 15, day 18, and day 21). Ten watermelons were randomly sampled from both the seeded and seedless watermelons for each storage day under the same storage condition. The same fruits were also used for both backscattering acquisition and destructive measurement.

2.2. Imaging system

In this study, a laser-induced backscattering imaging system which consists of a charge-coupled device (CCD) camera (QICAM Colour 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 a computer equipped with the Image-Pro Insight 9 software (Media Cybernetics, Inc., USA) was developed for acquiring the backscattering images. The CCD camera captured backscattering images of 1392 × 1040 pixels with a resolution of 0.073 mm/pixel and 12-bit gray colour depth. The portion of backscattering light upon penetrating into the fruit tissue was recorded by the CCD camera and stored on the computer. A frame (930 mm × 700 mm × 700 mm) with a lightproof medium i.e. black cloth was used to avoid interruption from ambient light. A laser diode at 658 nm is used as the light source which can distribute light for a selected wavelength. Since the processing of the whole laser-induced backscattering imaging system is quite fast, the image acquisition was set at a short exposure time (10 ms). The distance from the camera lens to the samples was set at 55 cm in a fixed position at the top of the fruit. The incident angle of the light beam was placed at 22° with respect to the vertical axis. The backscattering images were obtained by placing the sample manually on the sample holder facing the CCD camera. Backscattering images obtained at 658 nm from seeded and seedless watermelon samples during storage are shown in Fig. 1. Overall, a total of six images were acquired for each of the 140 samples of watermelon skin, thereby resulting in 840 backscattering images.

2.3. Backscattering image analysis

The backscattering images were obtained through an image segmentation process using Matlab software (Version R2013a, The Mathworks Inc., Natick, MA, USA). The region of interest in the image was selected by choosing the threshold value from a histogram profile based on the backscattering image (Fig. 2). From the feature extraction of the backscattering image, the pixel value (maximum intensity, minimum intensity, and mean intensity) and shape (major axis length, minor axis length, and perimeter) measurements were determined. The backscattering parameter measurements were then exported to Unscrambler software (Version 10.3, CAMO AS, Oslo, Norway) for further statistical analysis.

2.4. Multivariate pattern recognition algorithms

Linear discriminant analysis (LDA), quadratic discriminant analysis (QDA), and k-nearest neighbour (kNN) algorithms are different multivariate pattern recognition algorithms that can be used to classify the watermelon cultivars and storage days based on the backscattering parameters. These algorithms have been reported in the literature for different classification purposes, especially to classify spectral data sets (Liaghat et al., 2014; Sankaran et al., 2011). Before determining the overall classification accuracies of