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Rapid detection of browning levels of lychee pericarp as affected by moisture contents using hyperspectral imaging

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ABSTRACT

Lychee is an important tropical and subtropical fruit. However, the quality of lychee fruit changes easily after harvest and it is difficult to control the process. One of the most significant factors impacting lychee quality seriously is enzymatic browning, which is commonly affected by moisture loss of pericarp during storage. As an emerging technique, hyperspectral imaging (HSI) carries many unique advantages compared to conventional detection methods, providing an innovative tool for quality evaluation of many fruits. The current study focused on exploring the relationship between browning levels of lychee and moisture contents (MC) of pericarp, and developing calibration models for determining browning degree of lychee based on the MC prediction of pericarp using HSI technique. Two sets of optimal wavelengths were selected using regression coefficients (RC) from partial least squares regression (PLSR) and successive projections algorithm (SPA), respectively. Calibration models for determining browning levels of lychee were developed using PLSR, back-propagation neural network (BP-NN) and radial basis function support vector regression (RBF-SVR) algorithms and their performances were compared. The results demonstrated that the RBF-SVR model based on the optimal wavelengths selected by RC had the best performance with coefficients of determination R^2 of 0.946 and 0.948, and root mean square error (RMSE) of 0.80% and 0.83% for training and testing sets, respectively, showing browning levels of lychee could be determined by this approach. Finally, the visualization map of lychee with different browning levels was created and distribution of browning degree in a lychee was observed by examining color variation among pixels in the map.

1. Introduction

Lychee or litchi (*Litchi chinensis Sonn.*) is a popular tropical and subtropical fruit whose flesh is sweet, juicy and crisp. Lychee is favored by people around the world for unique flavor, wonderful taste and nutritive value. However, lychee is extremely easy to brown and the speed of lychee browning is much faster than other fruits like banana and longan, which increases the difficulty for its storage, transportation and marketing. Therefore, the industry is continuously looking for methods or techniques such as drying (Sun and Byrne, 1998; Sun and Woods, 1997; Delgado and Sun, 2002a, 2002b), refrigeration (Sun, 1997a,b; Sun et al., 1996; McDonald and Sun, 2001; McDonald et al., 2001; Kiani and Sun, 2011) and edible coating (Xu et al., 2001) for possible maintenance of its quality. Generally, lychee starts browning after being picked for 24 h at room temperature and pressure. The rapidity of lychee browning was mainly due to the moisture loss caused by evaporation on the surface of lychee according to Underhill and Critchley (1993). This is mainly caused by two reasons. One reason is that rapidly losing moisture causes cell damage of pericarp. Pericarp rapidly loses moisture after lychee being harvested. Attributed to completely separate structure of lychee pericarp and flesh, moisture loss of pericarp cannot be effectively supplemented by moisture existing in the lychee flesh, which makes pericarp desiccate and generates microcracks on the surface of the pericarp. Undoubtedly, such a drastic change in MC and the generation of microcracks lead to that pericarp cells are damaged and cytoplasm leaks. Another reason is that the loss of MC increases contact between anthocyanins and phenols, and polyphenol oxidase and peroxidase, accelerating enzymatic action (Underhill and Critchley, 1994). Thus, moisture in the pericarp plays a significant role in the process of lychee browning. However, at present, most of the studies available focus on how to inhibit browning and extend shelf life of lychee. Few studies

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are on the determination of browning levels of lychee. A few studies available mentioning browning levels only considered browning levels as one of the parameters for evaluating lychee quality, which was determined by simple visual inspection. For example, Joas et al. (2005) treated lychee with chitosan and organic acids for extending shelf life of lychee. Browning levels of the treated and untreated samples were determined by visually evaluating pericarp color and the results were compared for exploring the effectiveness of the method. Although some other studies (Huang et al., 2005) mention that lychee browning is affected by MC of pericarp, no study is available on not only the detailed relationship between browning levels and MC but also on the evaluation of browning degree of lychee based on MC of pericarp.

Recently, hyperspectral imaging (HSI) technique is increasingly applied to evaluation of fruit quality (Wu and Sun, 2013). The reason is that different from traditional methods such as titration, colorimetric method and chromatographic analyses, HSI combines the techniques of spectroscopy and imaging or computer vision (Sun, 2004; Sun and Brosnan, 2003; Jackman et al., 2008, 2009; Valous et al., 2009; Wang and Sun, 2002), simultaneously providing spectral and spatial information of fruits (Lorente et al., 2012; Lu and Chen, 1999). It overcomes many shortcomings of traditional methods such as tedious, time-consuming, destructive and not suitable for on-line applications (Cubero et al., 2011). Therefore in recent years, HSI has been widely studied for evaluating various food quality attributes (Barbin et al., 2012; ElMasry et al., 2011a,b, 2012; Kamruzzaman et al., 2011, 2012; Wu et al., 2012c). For fruits, the application of HSI is mainly in evaluating their physical and chemical compositions including color of apples (Noh and Lu, 2007), weight loss of avocados (Maftoonazad et al., 2011), firmness of peaches (Lu and Peng, 2006), MC of bananas (Rajkumar et al., 2012), total soluble solids of strawberries, sugar content of apples (Zhao et al., 2009), and anthocyanin concentration of grapes (Fernandes et al., 2011). HSI has also been implemented in several applications for the detection of diseases and blemishes such as rottenness of oranges (Li et al., 2012), citrus canker (Qin et al., 2008), bruises on apples (Lu, 2003), and fecal contamination on cantaloupes (Vargas et al., 2005). However, the use of HSI for estimating quality attributes of lychee is scarce, especially in evaluating browning levels of lychee as affected by MC of pericarp. It is a difficult task to detect quality attributes of lychee because of its shape and bumpy surface. The existence of fruit surface curvature makes light unevenly distributed on the surface of lychee. This leads to boundary area of hyperspectral images darker than central area, triggering the difficulty of spatial variation correction of hyperspectral images. In addition, bumpy surface of fruit makes it more difficult to evaluate its quality attributes by HSI (Huang et al., 2011).

Therefore, the aim of this current study was to investigate the potential of HSI for determining browning levels of lychee as affected by MC of pericarp during postharvest process. The approach included the following tasks:

(i) develop an HSI system working in 400–1000 nm and obtain hyperspectral images of lychees;
(ii) reduce the curvature effect during hyperspectral image correction using geometric correction factors;
(iii) select optimal wavelengths using two methods including regression coefficients (RC) from partial least square regression (PLSR) and successive projections algorithm (SPA);
(iv) build prediction models using PLSR, back-propagation neural network (BP-NN) and radial basis function support vector regression (RBF-SVR) algorithms, respectively and compare their performances; and to
(v) determine browning levels of lychee as affected by MC of pericarp and develop visualization map of browning degree and its changes of lychee during storage.

2. Materials and methods

2.1. Lychee samples and treatments

Defect-free lychees (*Feizixiao* variety, at commercial ripeness stage) were hand-picked in June 2013 from a local orchard in Guangzhou, China. In order to control the growth of germs on the surface of lychee, all fruits were dipped in 0.05% sporgon (the prochloraz-manganese chloride complex) (Hoechst Schering AgrEvo GmbH, Düsseldorf, Germany) for 2 min and air-dried at room temperature (Chen et al., 1997). The diameter of lychee fruits was measured by a digital caliper (ZC14365, Mahr GmbH, Göttingen, Germany) in two perpendicular directions. Lychees with diameter between 31.47 mm and 33.59 mm were selected as samples for study. All 360 samples were divided into 6 groups and stored in a stability chamber (SPX-300IC, Suzhou Jiangdong Precision Instruments Ltd., Suzhou, China) maintained at 25 °C and 75% RH for 0–5 days. Prior to each experiment, lychee samples were taken out from storage chamber and left for about 1 h to reach room temperature and then hyperspectral images of lychees were obtained using an HSI system. The acquired hyperspectral images were then imported into MATLAB software (2010a, The Mathworks Inc., Natick, MA, USA) for computing the ratio of the number of browning pixels to the number of total pixels. In this study, browning pixels were the pixels whose gray values were in the range of 0–0.24. The computed browning ratio was used to classify all samples into four browning levels: $1 \leqslant 5\%$ browning; 2 = 5–25% browning; 3 = 25–50% browning; $4 \geqslant 50\%$ browning (Joas et al., 2005).

2.2. Hyperspectral image acquisition and calibration

Lychee samples were scanned line by line using a pushbroom hyperspectral reflectance imaging system in the spectral range of 400–1000 nm. As illustrated in Fig. 1, the system is composed of five components: a spectrograph (ImSpector V10E, Spectral Imaging Ltd., Oulu, Finland) coupled with a standard C-mount zoom lens, a charged couple device (CCD) camera (DL-604M, Andor Co., Chicago, USA), two 150 W halogen lamps (Olympus Optical Co., Tokyo, Japan), a translation stage and a computer with the hyperspectral imaging analyzer software (V10E, Isuzu Optics Corp., Taiwan, China). For the purpose of obtaining high-quality image data, some scanning parameters were set before hyperspectral image acquisition. The distance between camera lens and upper surface of samples was 515 mm. Exposure time was 30 ms and the speed of translation stage was 1.6 mm/s for the whole experiment. Lychee samples were horizontally placed on a black tray fixed on the translation stage (Fig. 1), and then scanned line-by-line when the translation stage moved into the field of view of the camera lens. The actual size that a pixel corresponded to in the lychee sample was closely related to the distance between camera lens and samples. Under the condition of 515 mm distance, the size in both x and y directions was 0.128 mm. All these operations were conducted in a dark chamber.

In order to eliminate the effect of dark current of the CCD detectors and to make the spectral profiles more interpretable, the raw hyperspectral images were calibrated by a white and a dark references. The white image was obtained by recording the reflectance of a Teflon white board with 99% reflectance, while the black image was acquired by turning off all light sources with camera lens completely covered with an opaque cap. The calibrated image was calculated using the following equation:

$$R = \frac{R_0 - R_b}{R_w - R_b} \times 100\% \quad (1)$$