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Rapid detection of anthocyanin content in lychee pericarp during storage using hyperspectral imaging coupled with model fusion

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ABSTRACT

A quantitative approach was proposed to evaluate anthocyanin content of lychee pericarp using hyperspectral imaging (HSI) technique. A HSI system working in the range of 350–1050 nm was used to acquire a 3-D lychee image. Successive projection algorithm (SPA) and stepwise regression (SWR) algorithm were utilized to reduce data dimensionality and search for optimal wavelengths related with anthocyanin content in pericarp. Radial basis function support vector regression (RBF-SVR) was adopted to establish quantitative relationship between hyperspectral image information in two sets of optimal wavelengths and anthocyanin content of pericarp. Finally, in order to improve prediction accuracy, SPA-RBF-SVR and SWR-RBF-SVR models were fused into a single model by radial basis function neural network (RBF-NN) algorithm. The results revealed that the fused model possessed a better performance than either SPA-RBF-SVR or SWR-RBF-SVR models alone, as the fused model showed higher coefficients of determination (R^2) of 0.891 and 0.872, and lower root mean square errors (RMSEs) of 0.567% and 0.610% for the training and the testing sets, respectively. Visualization maps based on the fused model were generated to display the anthocyanin distribution within lychee pericarp. This study demonstrates that HSI is capable of predicting and visualizing anthocyanin evolution in the pericarp of lychee during storage.

1. Introduction

Quality is a very important factor for the development of the agricultural industry, Therefore methods and techniques such as drying (Sun and Byrne, 1998; Sun and Woods, 1997; Delgado and Sun, 2002a,b), 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) are often used to ensure product quality. Lychee or litchi (*Litchi chinensis Sonn.*), as a non-climacteric subtropical and tropical fruit, is one of the important agricultural products, especially in China, Vietnam and the rest of tropical Southeast Asia. At full maturity, its pericarp is bright red and white flesh is sweet and juicy. After harvest, the pericarp rapidly desiccates and turns brownness within 3 days at ambient temperature (Zhang and Quantick, 1997). Pericarp browning decreases commercial value of lychee and has been regarded as the major problem of postharvest lychee (Jiang et al., 2006). The rate of lychee browning is closely related to degradation of red pigments (identified as anthocyanins) and the formation of brown-colored by-products (Huang et al., 1990; Lee and Wicker, 1991). Therefore, anthocyanins are considered as one of the most significant parameters for evaluating lychee quality and are increasingly used to grade fruits into different quality levels. Therefore besides utilizing technologies for keeping its quality, it is equally important to develop methods for evaluating its quality. The available methods for assessing anthocyanin content are commonly based on ultraviolet-visible spectrophotometry (Joas et al., 2005) and chromatographic analyses (Zhang et al., 2003). These methods are functional but inefficient and difficult to be applied to on-line inspection of anthocyanin content. Consequently, there is a need for rapid and non-contact techniques to inspect the fruit quality.

Hyperspectral imaging (HSI) is a cutting-edge optical technique that combines imaging or computer vision (Sun and Brosnan, 2003; Valous et al., 2009; Jackman et al., 2008; Sun, 2004; Patrick et al., 2009; Wang and Sun, 2002) with spectroscopic techniques into a single system (Wu and Sun, 2013a,b). It can continuously and

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rapidly scan fruit samples and simultaneously provide spectral and spatial information for each pixel, making it carry a great potential in non-destructively detecting food quality attributes and visualizing their spatial distribution (Cubero et al., 2011; Kamruzzaman et al., 2011, 2012; ElMasry et al., 2011a,b, 2012; Barbin et al., 2012; Wu et al. 2012c). The feasibility of using HSI for evaluating pigments of fruits has been demonstrated by Fernandes et al. (2011), in which a visible-near infrared (Vis-NIR) HSI (400–1000 nm) system was developed to determine anthocyanin concentration of grape (*Cabernet Sauvigon* variety) skins. Adaptive boosting neural network algorithm was adopted to establish calibration model of anthocyanin content. The principal components of grapes' spectra were the inputs of the adaptive boosting neural network, and anthocyanin concentrations measured using conventional laboratory techniques were the outputs. A squared correlation coefficient of 0.65 was achieved, which revealed how beneficial the development of a neural network performance could be. In another study, Qin and Lu (2008) measured optical properties of fruits (apples, peaches, pears, kiwifruits and plums) and vegetables (cucumbers, zucchini squash and tomatoes) by Vis-NIR (500–1000 nm) HSI. Three major pigments; i.e., chlorophyll, anthocyanin and carotenoid, were investigated. A good correlation was found between diffuse reflectance spectra of samples and the three pigments concentrations.

The above several studies were the only papers available on determining pigments of fruits by HSI. At present, no research has been done on application of HSI for evaluating pigment content of lychee fruits, especially anthocyanin content of pericarp. The lack of such studies may be because it is quite difficult to estimate pigment content of lychee by HSI due to its short shelf life, shape and bumpy surface. Lychee is a seasonal fruit with the marketing time of 2–3 months and the shelf life of only 3–5 days, leading to that the quality of lychee is ever-changing. This increases the difficulty of measuring quality attributes of many lychee samples in the same conditions using traditional methods for developing prediction models. Furthermore, the curvature of lychee fruit can cause an uneven distribution of light on its surface when it is irradiated by a light source, causing the peripheral area of lychee darker than the central area in the measured hyperspectral image. In addition, as noted by Huang et al. (2011), bumpy surface of

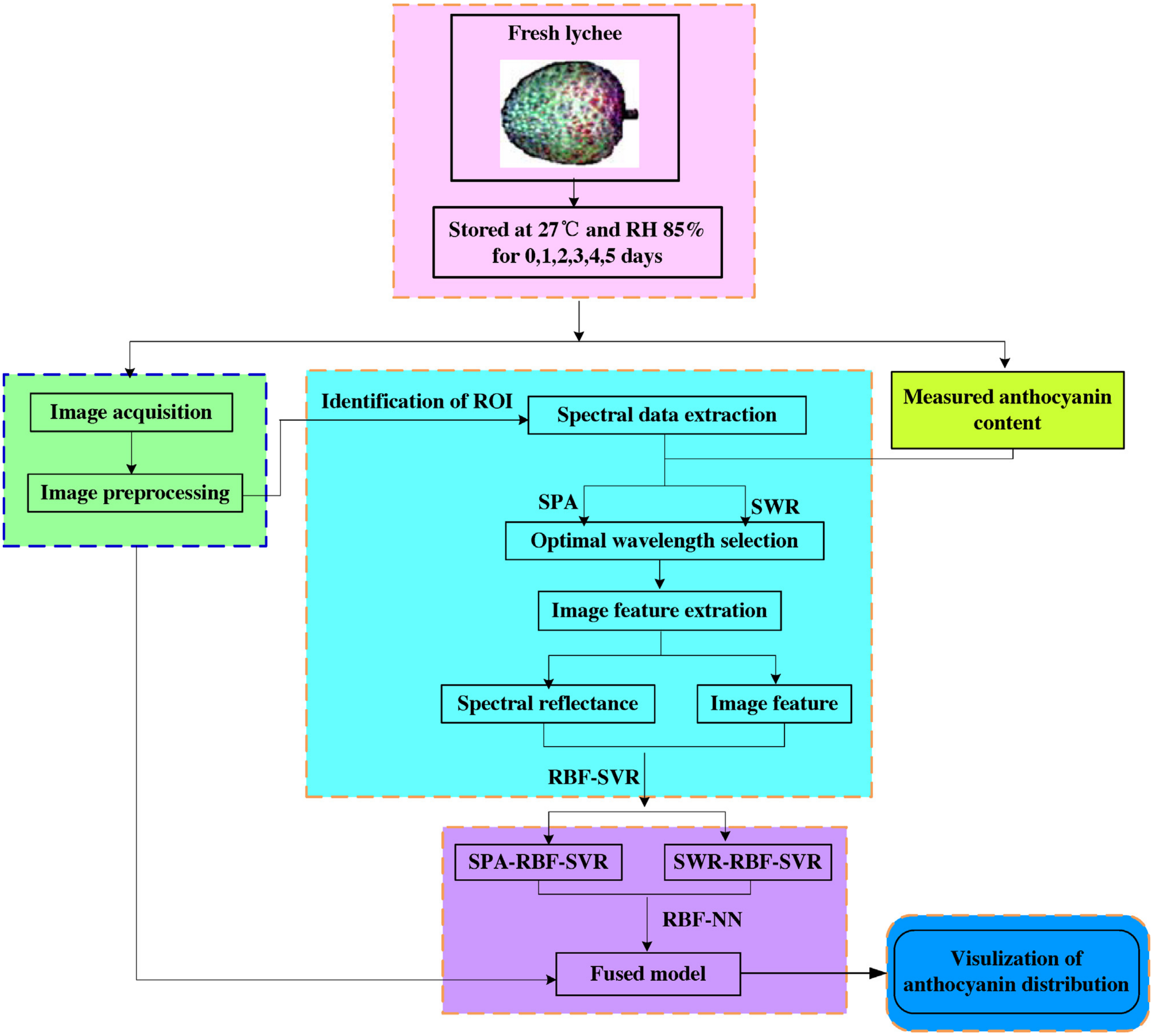

Fig. 1. Key steps of the experimental procedure and data processing.
ROI: region of interest; SPA: successive projection algorithm; SWR: stepwise regression; RBF-SVR: radial basis function support vector regression; RBF-NN: radial basis function neural network.