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Hyperspectral imaging with different illumination patterns for the hollowness classification of white radish

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ABSTRACT

This study presented the detection of hollowness in the worldwide important vegetable crop white radish (*Raphanus sativus* L.) by using hyperspectral imaging covering the spectral range of 400–1000 nm. The hyperspectral images based on the three illumination patterns of reflectance, transmittance, and semi-transmittance were acquired from white radishes. The successive projections algorithm (SPA) was used to identify the optimal wavelengths from the three patterns of spectra. Two classifiers of partial least square discrimination analysis (PLS-DA) and back propagation artificial neural network (BPANN) were established based on the full wavelengths and selected wavelengths. Discrimination models were performed for the two-class, three-class, and five-class hollowness classifications using the mean spectra from the regions of interest (ROI) in the spectra images. The classification results showed that hyperspectral semi-transmittance imaging combined with the BPANN model performed the best classification accuracy for the two-class hollowness classification based on the full and selected wavelengths reaching 98% and 97% for the calibratio`n and the prediction sets, respectively. Lower accuracies were obtained for the three-class and five–class hollowness classifications based on the combination of classifiers and illumination modes. The results demonstrated that hyperspectral semi-transmittance imaging was potentially useful as a non-invasive method to identify the hollowness in white radishes.

1. Introduction

For white radish (*Raphanus sativus* L.), hollowness is a physiological disease that easily occurs during growth and postharvest storage. It can reduce the dry matter and increase the crude fiber content of radishes, which severely affects the quality of processing, eating, and storage (Shang et al., 2015). Hollowness, however, is difficult to detect by visual inspection as the defects are characterized by cavities or space, and lignification inside the radishes (Kano and Fukuoka, 1996; Fukuoka and Kano, 1997). Currently, hollowness is still assessed by sensory panels based on human inspection in a destructive way. A sensory panel is only suitable for testing a small number of vegetables, and is often subjective, time consuming and labor-intensive. Hence, an effective, rapid, objective and nondestructive method is needed for detecting defective radishes.

A number of nondestructive methods have been investigated for the internal quality of fruits and vegetables, such as near infrared spectroscopy (NIRS) to detect soluble solids content (SSC) and titratable acidity (TA), pH, firmness in passion fruit, tomato and apricot (de Oliveira et al., 2014), watermelon (Jie et al., 2014), pear (Li et al., 2013), pineapple (Chia et al., 2012), and sugar beet (Pan et al., 2015). Acoustic and impact methods were developed for the firmness prediction in peach (Diezma-Iglesias et al., 2006) and watermelon (Mao et al., 2016). Magnetic resonance imaging (MRI) was applied for the evaluation of tomato maturity (Zhang and McCarthy, 2012). Generally, these methods are also able to detect the internal defects of fruits and vegetables as illustrated by using NIRS to detect brown core in the Chinese pear “Yali” (Han et al., 2006), brown heart in Braeburn apples (Clark et al., 2003; McGlone et al., 2005), and internal defects in Japanese radishes (Takizawa et al., 2014). MRI was developed to probe the watercore development in apples (Melado-Herreros et al., 2013). Acoustic impulse responses were tested for detecting internal defects of seedless watermelon (Diezma-Iglesias et al., 2004). Among the mentioned methods above, NIRS is the most advanced technique for evaluating the internal quality including defects in fruits and vegetables (Sun et al., 2010; Khatiwada et al., 2016). Nevertheless,

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it lacks highly resolved spatial information, which limits the performance of detecting internal defects that appear inhomogeneously inside the samples.

However, hyperspectral imaging was developed by combining conventional imaging and spectroscopy for quality and safety evaluations of fruits and vegetables (Pu et al., 2015). Many applications of hyperspectral imaging for quality evaluation have been reported with satisfying accuracies when using appropriate illumination patterns (i.e., reflectance, transmittance, and semi-transmittance) (Hu et al., 2015). Examples include the determination of the firmness and SSC of blueberries (Leiva-Valenzuela et al., 2012), SSC, pH and anthocyanin contents in grape berries (Fernandes et al., 2015), bruise in apples (Xing and De Baerdemaeker, 2005), and the internal defects (i.e., watery and split/hollow) and chilling injuries in cucumbers (Cen et al., 2014, 2016). Chilling injury was also detected in apple (ElMasry et al., 2009) and peach (Pan et al., 2016). Furthermore, full hyperspectral imaging can be developed for real-time, online inspection, and multispectral imaging based on waveband selections reducing redundant imaging features, information processing time and cost. In-house developed on-line grading hyperspectral imaging systems were reported for the quality evaluation of food and agricultural products, such as the detection of internal defects of pickling cucumbers (Cen et al., 2014), bruises on apples (Huang et al., 2015), and the acidity and moisture and peroxide content in olive oil samples (Martínez Gila et al., 2015).

Therefore, this work investigated the potential of using hyperspectral imaging to detect hollowness in white radishes. The specific objectives were: (1) to develop a technique to detect hollowness of white radishes using hyperspectral imaging in the spectra range of 400–1000 nm; (2) to select effective wavelengths for the hollowness classification; 3) to compare the performance of classification based on different modes (reflectance, transmittance, and semi-transmittance) and classifiers based on partial least squares discrimination analysis (PLSDA) and back propagation artificial neural network (BPANN) models.

2. Materials and methods

2.1. White radish samples

A number of 440 commercially-mature white radishes (*Raphanus sativus* L., No. 301) were obtained from a farm located at the Jiangsu Province, China. The samples were similar in size (70.7 ± 3.68 mm diameter, 278.3 ± 8.49 mm length) and shape, and were free of external defects based on a visual inspection. Hollowness was reached by storing all the samples at a constant temperature of 5 ± 1 °C in a chamber containing a constant relative humidity of 90%. The radishes were sliced into four sections along the longitudinal axis and the hollowness levels were visually evaluated by ten trained persons. Typical normal and hollow radish slices at different levels are shown in Fig. 1. Each sample was categorized into one of the five hollowness levels: “normal” (level 0, without hollowness, Fig. 1a), “slight hollowness” (level 1, sample with some punctuated, linear, and white lignified tissue, Fig. 1b), “moderate hollowness” (level 2, sample with a large area of lignification, Fig. 1c); “grave hollowness” (level 3, sample with a small cavity and severe lignification, Fig. 1d); “extreme hollowness” (level 4, sample with large cavities and complete lignification, Fig. 1e).

The quality attributes for each different hollowness level, moisture content, crispness, quantity of crude fiber and of lignin were determined for 140 white radishes (out of the 440 samples) which were stored for 120 days. Due to individual differences, the hollowness level was not the same despite radishes sample were stored equally long. Therefore, 20 samples were taken for every 20 d from the chamber and individually inspected for hollowness.

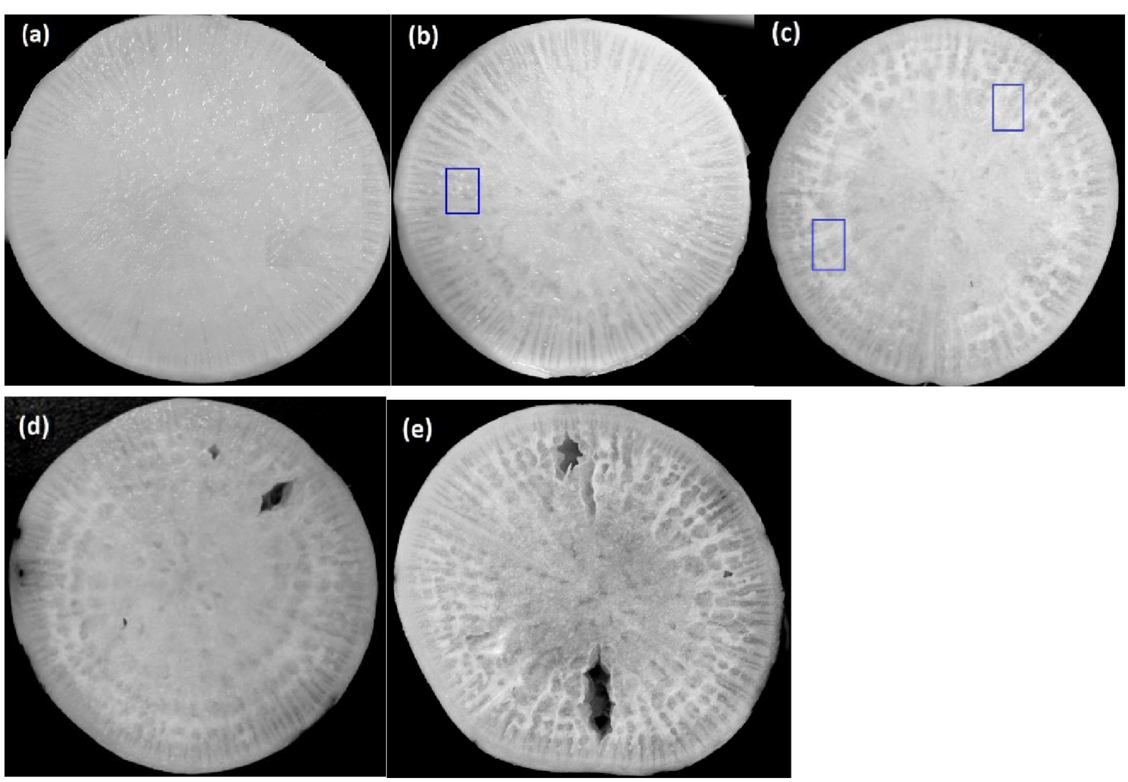

Fig. 1. Hollowness at different levels of white radishes (a: Level 0; b: Level 1; c: Level 2; d: Level 3; e: Level 4).