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Development of nondestructive technique for detecting internal defects in Japanese radishes

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ABSTRACT

Numerous vegetable types, such as the large Japanese radish known as “*daikon*” are prone to internal defects that are impossible to detect with the human eye. Nondestructive measurement provides a suitable technique for detecting defects such as black heart, and air cavities that make such radishes unmarketable. In this paper, we report on the development of a nondestructive detection algorithm for visible/near infrared (Vis/NIR) spectroscopy that can be used to detect internal defects in Japanese radishes. Using the first derivative, selected Vis/NIR wavelengths were calculated by a stepwise forward selection method and then used as classifying parameters in a LDA, PLS-DA, and a neural network. The LDA and neural network were then used to build the detection algorithm based on leave-one-out cross validation. The PLS-DA was then used to build the detection algorithm based on double loop leave-one-out cross validation. When the LDA and PLS-DA were used for the prediction set (removed samples), both of the overall discriminant rate were 90.1%. When the error goal was 0.05 and the number of hidden neurons was 13, the discriminant rates for normal radishes, radishes with internal defects, and the total for all samples were 97.0%, 82.9% and 92.4%, respectively. These results show the potential of the proposed techniques for detecting defects and predicting the internal quality of Japanese radishes.

1. Introduction

Approximately 1.6 million tons of the large Japanese radish type known as “*daikon*” are grown each year in Japan, making it the nation’s second most harvested vegetable behind the potato. Niigata prefecture is the fourth most planted area for the fall and winter radish, most of which are shipped to suppliers for use as the raw materials for “*takuan*” pickles. Since *takuan* are pickled whole and uncut, the value of the product falls markedly when internal defects exist in the radish. Such defects, including black heart and air cavities, make the radish unmarketable but are impossible to detect with the human eye alone. Therefore, a form of nondestructive testing is needed to detect internal defects in the vegetable after harvest.

Visible/near infrared (Vis/NIR) spectroscopy is in wide spread use in the agricultural products industry where it is employed to detect the internal quality of a variety of products, such as sugar content in *satsuma* mandarin oranges (Kawano et al., 1993), soluble solids and firmness (Fan et al., 2009), brown shell eggs with blood spots (Nakano et al., 2004), translucent fresh disorder in intact mangosteen (Teerachaichayut et al., 2007), and brown heart in Braeburn apples (McGlone et al., 2005).

In addition, Vis/NIR spectroscopy combined with a neural network is used in several agricultural product industries for classification purposes, such as determining the discriminant rates of Chinese bayberry varieties (Li et al., 2007), classifying instant milk tea varieties (Liu et al., 2009), and the classification of Duroc and Iberian pork (Del Moral et al., 2009).

This study describes the development of a nondestructive technique for detecting internal defects in Japanese radishes by Vis/NIR spectroscopy using multiple discriminant analysis and/or neural networks.

2. Materials and methods

2.1. Samples

For this study, 228 Japanese radishes (harvested in Akatsuka, Nishiku, Niigata city) were collected. After data acquisition, the samples were cut and classified as either “normal” or “internal defects” by visual inspection.

The internal defects observed varied in both size and color, with most falling into one of two categories: blackish-brown internal

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spots (known as black heart) and air cavities. The black heart defects, were classified by size (above or below 10 mm in diameter), while the air cavities were classified by internal color (colorless or black) and were between 1–40 mm in diameter (see Fig. 1).

After classifying the 228 samples by visual inspection, it was found that 130 were normal, five had "large" black heart defects, 25 had "small" black heart defects, six had "colorless" air-cavity defects, and 62 had "black" air-cavity defects. For the following analysis, the 130 normal samples and 62 "black" air-cavity defects were used. The other classes were set aside due to their small numbers.

2.2. Experimental apparatus

The experimental apparatus used in this study consisted of two 150 W tungsten halogen light sources (PICL – NEX TWIN, NIPPON P.I. Co., Ltd., Tokyo, Japan), a spectrometer (Handy Lambda II, Spectra Co-op Co., Ltd., Tokyo, Japan) in the range of 310–1100 nm with a 3.3 nm sampling interval, a dark sample compartment, and a personal computer (PC). An overview of the experimental setup is shown in Fig. 2. The optical fiber that was connected to the light source was positioned to irradiate one side of the sample radish, while on the other side, the optical fiber for light reception, which is connected to the spectrometers, was positioned to receive the transmitted light. The spectrometer was connected to a PC with USB 2.0. and Vis/NIR spectra data were collected and transformed using Wave Viewer software (Spectra Co-op Co., Ltd., Tokyo, Japan).

2.3. Spectra data analysis

The light intensity spectra acquired by the spectrometers were affected by various conditions, such as the sample thickness, light attenuation, and the measurement environment. Therefore, a reference spectrum (a 2.5-mm-thick white ceramic plate) and a dark spectrum were obtained. The transmittance was calculated by the following equation:

$$T = \frac{\text{sample} - \text{dark}}{\text{reference} - \text{dark}} \tag{1}$$

where T is the transmittance, and sample, reference, and dark are the light intensities at each wavelength for the sample, reference and dark spectra, respectively.

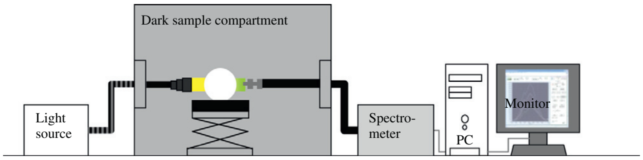

Fig. 2. Experimental apparatus.

The absorbance, A, was then calculated by Eq. (2) for the measurement range of 612–825 nm. Using the absorbance, the first derivative was calculated with the Savitzky–Golay method (Savitzky and Golay, 1964).

$$A = \log_{10}\left(\frac{1}{T}\right) \tag{2}$$

2.4. Feature selection

The use of the selected wavelengths for classification purposes is an adequate strategy because it can avoid the so-called "curse of dimensionality" (Acevedo et al., 2007). Using the first derivative, the selected wavelengths were calculated by stepwise forward selection method. This method is a process in order to continue to select a largest F-value. At that time, to enter F value was set to 2.0; to remove F value was also set to 2.0.

2.5. Discriminant analysis

Linear discriminant analysis (LDA) and partial least squares discriminant analysis (PLS-DA) were used to discriminate between normal radishes and those with internal defects. LDA was performed to build a model for classification, using the first derivative absorbance spectra at the selected wavelengths as the independent variables, and using the data from the normal radishes and radishes with internal defects as the dependent variable. The boundary between the normal and internal-defect sample was defined by the LDA Eq. (3). PLS-DA was performed to build a model for classification, using the first derivative absorbance spectra as the independent variables, and using the data from the normal radishes and radishes with internal defects as the dependent variable. The

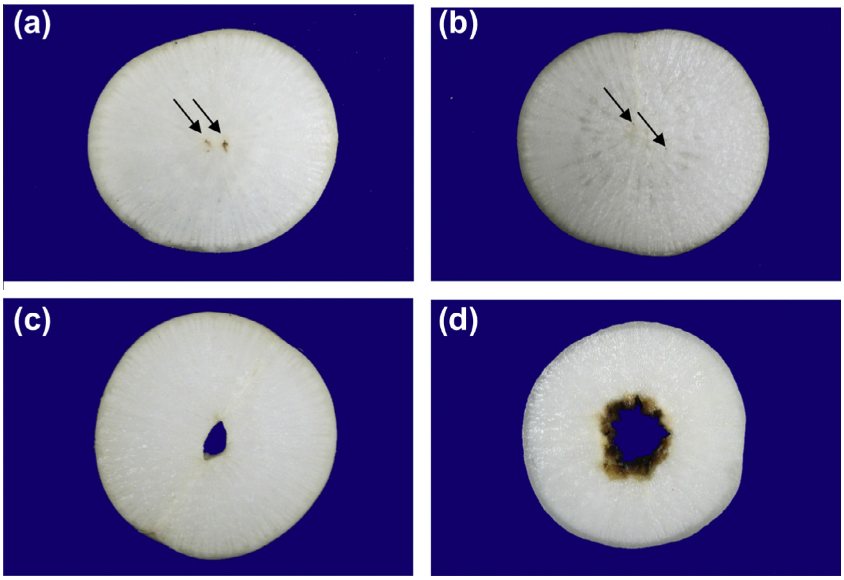

Fig. 1. Cross-section of a sample radish: (a) "large" black heart, (b) "small" black heart, (c) "colorless" air cavity and (d) "black" air cavity.