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Pears characteristics (soluble solids content and firmness prediction, varieties) testing methods based on visible-near infrared hyperspectral imaging

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ABSTRACT

Visible-near infrared hyperspectral images (400–1000 nm) were used for non-destructive variety discrimination and prediction of soluble solids content (SSC) and firmness of pears. An imaging spectroscopy system was assembled to acquire scattering images from pears. Spectra of 180 pear samples from three varieties were analyzed by four algorithms of principal component analysis (PCA), partial least squares (PLS), successive projections algorithm (SPA) and Fisher linear discriminant analysis (Fisher LDA) to detect SSC, firmness and varieties of pears. Then PLS models under whole spectral wavelengths were compared with SPA-PLS models under effective wavelengths. The SPA-PLS models were considered to be the best method for detecting firmness and SSC of pears. The model led to correlation coefficient (r) of 0.9977 for firmness and 0.9924 for SSC and root mean square error (RMSEP) estimated by cross-validation of 0.062653 for firmness and 0.03175 for SSC. The correct answer rate of 95.56% for variety discrimination was achieved by Fisher LDA.

1. Introduction

Pears are nutritional fruits which are one of the important fruits consumed all over the world. Different varieties of pears are of quite different tastes and qualities. Fresh pears need to meet certain quality grade requirements before they are shipped to the marketplace. These requirements include fruits outward characteristics and internal quality attributes (such as firmness, pH, acid, sugar, etc.). Soluble solids content (SSC) and firmness are two important internal quality attributes in determining fruit maturity and harvest time, and in assessing and grading post-harvest quality of pears. Currently, destructive techniques are routinely used for measuring fruit SSC and firmness. Thus, a fast, non-destructive and reliable approach to measure internal quality (firmness, SSC, pH, etc.) of fruit is in strong need of varieties discrimination and quality evaluation.

Recently, hyperspectral imaging system (also called imaging spectrometry system) is getting a growing interest and attention as a rapid and noninvasive analytical tool in many fields. It can be used to detect inner properties of food [1–4], bruises of fruit [5–7], ripeness of fruit [8–10]. By integrating two classical optical sensing technologies of computer vision and spectroscopy into one system, hyperspectral imaging can generate a spatial map of spectral variation, resulting in the capability of quantitatively determining the inherent chemical and physical properties of the specimen as well as their spatial distribution simultaneously.

Visible and near infrared (VNIR) hyperspectral system is widely used for rapid, low-cost and non-destructive analysis of varieties discrimination and inner properties such as firmness, SSC and pH of fruits such as apple [11–14], tomato [15–18], banana [19–22] and pear [23]. If the performance based on effective wavelengths could be close to whole spectra, obtained effective wavelengths can be used to develop inexpensive on-line sensors and instruments for nondestructive determination and SSC and firmness prediction of pears and for the industrial application.

VNIR imaging spectrometry has not meant used yet to detect varieties determination and firmness and SSC prediction of pears. The objective of this paper was to find applicable testing methods based on VNIR imaging spectrometry to predict SSC and firmness and to determinate varieties of pears.

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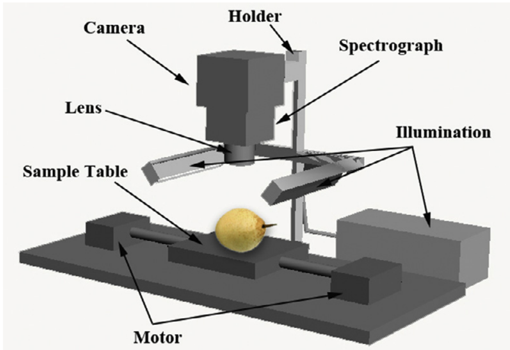

Fig. 1. Schematic diagram of the main components of the imaging spectrometry system.

2. Materials and methods

2.1. Sample preparation

Snow pears, Crown pears and Tianjing pears were picked 60 of each variety in a credible fruit market in Shanghai. Only those pears that were free from blemishes and bruises by visual inspection were selected for the study to ensure the accuracy of the experiment. Each sample was individually numbered. They were stored in an ice filled cooler to keep a certain temperature (about 0.5 °C). It's the best condition to hold pears fresh [24]. Thirty fruits for each cultivar were selected for predicting model to predict firmness and SSC and other ninety pears were used to determinate varieties. All samples were first allowed to equilibrate to room temperature (25 °C) before imaging spectrometry experiment.

2.2. Reference values

In this experiment, the firmness and SSC of pears were predicted by the model set by PLS combined with the spectral information detected by the imaging spectrometry system and the reference value of firmness and SSC of the pears. The sclerometer (Model GY-3, range 0.5–240.1 kg/cm^2) manufactured by HANDPI Company, China was used to measure the reference value of firmness. Refractometer (Model LH-T32, range 0–32%, accuracy 0.2%) manufactured by LOHAND HOLDING LIMITED Hangzhou Lohand Biological Co., Ltd., China was used to measure the reference value of SSC. The values are showed in Table 1. All of these measurements were performed immediately after Vis–NIRS measurements.

2.3. Imaging spectroscopy system

Each pear was imaged individually in the line scan push broom imaging spectrometry system illustrated in Fig. 1. The developed imaging spectrometry system mainly consisted of a imaging spectrograph (ImSpetorV10E, Spectral Imaging Ltd., Oulu, Finland) covering the spectral range of 400–1000 nm, a high-resolution 1392 × 1040 digital camera (Imperx, IGV-B1410M-SC000, USA) for the spectral range of 400–1000 nm and the size of 8.978 × 6.708 mm, a camera lens (Schneider Kreuznach, Germany) for the spectral range of 400–1000 nm and the numerical aperture of 2.4, two computer operating the imaging spectrograph software (Spectral Image-VINR and HIS Analyzer, Wuling Company, Taiwan, China) which can control exposure time, wavelength range, and generate spatial maps and extract useful spatial information, an assembled light unit consisting of two 150-W quartz tungsten halogen lamps as the light source (Model 3900, Illumination Technologies, Inc., New York, USA), a conveyer belt operated by a stepper motor (Model WN232TA300M-F, Weinaguangke Company, Beijing, China), and a computer operating the Imaging Spectroscopy System software (DyiTV1.1.5, Weinaguangke Company, Beijing, China) which controls the motor speed, accelerated speed and distance. To get the same spatial shape of objective in the image, we should to adjust the speed of the motor at 400 μm/s. The illumination was focused on the surface of the pears at the same height with the camera lens' focal plane. The width of each light line on the pear was 12 mm, which is enough for the detector's field of view. The camera lens was positioned 330 mm above the surface of the samples and the height can be controlled at ±10 mm to get the best image. The resolution of the imaging spectrograph is 2.73 nm. The pears move on the *X*-axis direction while the detector holds still and the linear slit of the detector scanning along the *Y*-axis, resulting in the achievement of the generation of the spectral image. The spectral range of the Imaging Spectroscopy System is 375–1026 nm with 1040 spectral bands. But the range of 375–400 nm is useless. The imaging spectrometry system was calibrated following the procedures described in Lu et al. [24].

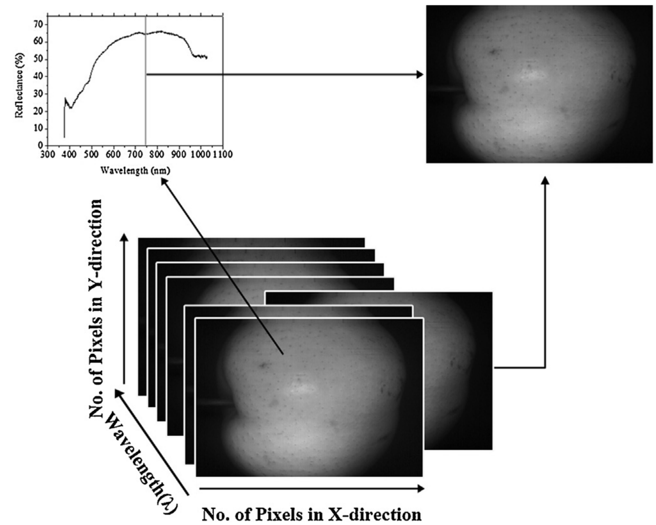

Fig. 2. Hyper spectral imaging.

2.4. Image acquisition

By using the line push broom imaging spectrometry system, each pear was placed on the sample table to be scanned by the linear slit of the detector at the speed of 400 μm/s to build a spectral image with a dimension of (X, Y, λ). Two dimensions of the *X*-axis direction and the *Y*-axis direction represented the spatial information and the third dimension of the λ-axis direction represented the spectral information. A two-dimensional image (Y, λ) was acquired at a time and with the pears moving on the *X*-axis direction, a complete hyperspectral cube was acquired eventually (Fig. 2).

2.5. Correction of hyperspectral images

To get the reflectance hyperspectral image, the original image should be calibrated with white and dark reference images. The white one (W) was acquired under the same condition of the raw images (P) using a white surface board made by Teflon (about 99.9% reflectance). The dark reference image (D_1) was obtained when the light source was turned off and the camera lens was completely covered with its opaque cap and was used to remove the effect of dark current of the camera sensor. The sample dark reference image (D_2) was acquired at the same exposure time with the raw