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Hyperspectral image-based multi-feature integration for TVB-N measurement in pork

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ABSTRACT

Total volatile basic nitrogen (TVB-N) content is an important index used to evaluate the freshness of pork. In this paper, a strategy for measurement of TVB-N content in pork through hyperspectral imaging (HSI) (400–1000 nm) was developed. Firstly, image textural features based on Gabor filter and spectral features were obtained from the hyperspectral image after determining the region of interest. Then, nine feature wavelengths were selected using partial least-squares projection algorithm. And, major components were obtained from the 2D principal component analysis (2DPCA). Finally, a calibration model was established based on major components using least-squares support vector machine to predict TVB-N values. The results of two methods for data fusion, which are 2DPCA and principal component analysis (PCA), are compared. The correlation coefficients of prediction (R_P) and root-mean-square errors of prediction (RMSEP) obtained through 2DPCA were 0.955 and 1.86 mg/100 g respectively, which was superior to the results based on PCA ($R_P = 0.944$, RMSEP = 2.07 mg/100 g). Compared to PCA, the residual prediction deviations (RPD) based on 2DPCA was raised from 3.01 to 3.35. Results demonstrated that the proposed model based on 2DPCA exhibited potential for nondestructive detection of TVB-N content in pork.

1. Introduction

Pork products are commercially important and widely consumed as food. Raw pork meat, as one of the most perishable foods, is easily contaminated by unavoidable infection and subsequent decomposition of meat by bacteria and fungi (Schirmer and Langsrud, 2010). Scholars have increasingly focused on meat quality and safety, which are desired characteristics in the modern meat industry. Meat quality and safety comprise many attributes, such as color, texture, pH, and freshness (Guan et al., 2014; Hui et al., 2014). Freshness is an important parameter used to assess meat quality (Leroy et al., 2004). Total volatile basic nitrogen (TVB-N) is one of the most widely used reference indices for evaluating freshness; TVB-N is composed of toxic small-molecule substances and non-protein nitrogenous compounds (Rodtong et al., 2005; Cai et al., 2011; Lee et al., 2017). TVB-N content can be determined through various existing methods, such as semi-micro nitrogen determination and micro-diffusion (Zhang et al., 2008). However, these analytical methods are not only destructive and time consuming but also incompetent for modern industrial processing. Therefore, rapid, accurate, and nondestructive analytical techniques must be developed to assess pork freshness.

Hyperspectral imaging (HSI) (Kamruzzaman et al., 2012) is a powerful technique that integrates conventional computer imaging and spectral analysis to obtain spatial and spectral information from an object. HSI is used for nondestructive evaluation of food quality and safety (Liu et al., 2014; Xiong et al., 2015), and to predict meat freshness (Huang et al., 2013; Li et al., 2016; Ye et al., 2016). Hereafter, TVB-N, which was one of the most important indexes in evaluation of meat freshness, is predicted by HSI (Chen et al., 2013). Some studies have used spectral feature to predict TVB-N content (Zhang et al., 2012; Yang et al., 2017). However, the process of pork spoilage is intricacy. The spectrum information is able to prove chemical properties and can't describe some fundamental information (color and texture, etc.), which play an important role on predicting quality of meat and meat products (Huang et al., 2013; Pu et al., 2015). In order to fully explore the spatial and spectral

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advantages of HSI and improve prediction accuracy of TVB-N of meat, some studies have been conducted to predict TVB-N of meat by using hyperspectral characteristics and texture features (Khulal et al., 2016, 2017). Characteristic variables from colorimetric sensor array, spectral and image variables were extracted from hyperspectral images and were then integrated for rapid prediction of TVB-N of pork in Li et al. (2015), and the model based data fusion exhibited a prediction accuracy of 0.932, which was better than that based on spectral or image variables alone. Nevertheless, in Li et al. (2015), it increased the additional cost of equipment using colorimetric sensors and the algorithm using data processing was complicated. Meanwhile, multiple features were combined by principal component analysis (PCA) for data fusion to eliminate feature redundancy and improve model performance in most of studies (Huang et al., 2014a,b; Li et al., 2015), but PCA is based on 1-dimensional vector, which may ignore the structural information of features. Therefore, it is necessary to find the new method for extracting features from HSI and the way for features fusion. Two-dimensional Gabor can achieve certain optimal joint localization properties in the spatial domain and in the spatial frequency domain and can be used to extract multi-scale and multi-directional texture features of images. Therefore, it is of interest to obtain Gabor texture of HSI in this study. Two-dimensional principal component analysis changes feature vectors into two-dimensional feature matrix, which not only doesn't lose the original features information but also may add additional structural information of features in the process of change (Yang et al., 2004). Hence, this work proposes the use of the 2DPCA strategy for feature fusion in order to improve the prediction accuracy of TVB-N.

In this study, the potential of hyperspectral imaging technology was exploited for the detection of TVB-N in pork meat. Specifically, this study aims to (1) select feature-related wavelengths by using partial least-squares (PLS) projection algorithm; (2) extract spectral data and texture features from the hyperspectral images; (3) data fusion based on spectral data and texture features using the 2DPCA strategy; and (4) measure TVB-N content in pork meat by least-squares support vector machine (LSSVM).

2. Materials and methods

2.1. Meat materials and sample preparation

Fresh pork longissimus muscles were purchased from a local super market and transported to the laboratory within 30 min. The 186 samples were trimmed, with size of 5 cm × 4 cm × 2.5 cm (*length* × *width* × *thickness*). Each sample weighed approximately 50 g, individually packed in a sterilized tray, over-wrapped with low-density polyethylene film, and stored in a refrigerator at 4 °C for 1–21 days. On each day of the experiment, ten samples were taken out randomly for optical imaging and reference microbiological tests on the 1st–14th days and 17th–20th days, and the six remaining samples were completed on the 21st day. TVB-N content in the samples minimally changed on the 11th–14th days, so the experiment was not performed on the 15th–16th days. Before each experiment, the samples were removed from the fresh-keeping film layer and exposed in air for 30 min to eliminate effects caused by surface water of samples and tissue coagulation.

2.2. Hyperspectral image acquisition

A line-scan hyperspectral imaging system in the visible/NIR range of 400–1000 nm was used to acquire images of pork in reflectance mode (Xiao et al., 2014). This integrated system comprises a charge-coupled device (CCD) camera (Pixelfly QE IC*285AL, Cooke, USA), imaging spectrograph (1003A-10140 Hyperspec TM VNIR C-Series, Headwall Photonics Inc., Fitchburg, USA), zoom lens (10004A-21226 Lens, F/1.4 FL23 mm, Standard Barrel, C-Mount., USA), illumination unit with 150 W tungsten halogen lamps (Halogen lamp, EKE, 3250 K, Techniquip, USA) equipped with single-optic fiber, translation stage, and computer supported data acquisition program and control software (Hyperspectral Scanning and Image Rendering Software, Rev A.2.1.3, Headwall Photonics Inc., Fitchburg, USA). The CCD area detector of the camera comprises 1392 × 1024 pixels and an imaging spectrograph for effective spectral range within 400–1000 nm. The whole image of one tested sample was acquired under 70 mm scan length and 80 μm step size. The tested sample at horizontal motorized stage was automatically moved to the pre-determined initial position. The horizontal stage started to move horizontally, as synchronized with the acquisition of the camera of hyperspectral images from tested sample. A total of 875 scans covering 70 mm distance were acquired at a constant exposure time of 180 ms. The hyperspectral images possessed 6.4 nm spectral resolution per pixel covering the spectral region of 400 nm to 1000 nm and 94 wavelengths of each sample were obtained after 10 spectral binning operations. Thus, a special block of 1392 × 875 × 94 hyperspectral image was achieved. The entire data acquisition process was conducted in a closed black box to minimize the interference of external light source.

2.3. Reference measurement

The hyperspectral images of the pork samples were used to immediately determine TVB-N content through semi-micro Kjeldahl method (GB/T5009.442003) (China National Standard) as standard for assessment of meat freshness (Yang et al., 2017). In the reference measurement, fat and pig skin were removed from the test samples and ground three times by using an A-88 meat grinder with 4 mm holes. Ten grams of the ground pork sample was placed into a beaker, blended with 100 mL of distilled water, and impregnated for 30 min. The beaker was shaken every 10 min, and the solution was filtered using filter paper. The filtrate (5 mL) was made alkaline by adding 5 mL of 10 g/L magnesia (MgO). Steam distillation was performed using a Kjeldahl distillation unit for 5 min. The distillate was absorbed by 10 mL of 20 g of boric acid and titrated with 0.01 mol/L HCl solution. TVB-N content was calculated using the following equation:

$$TVB-N(mg/100g)=\frac{(V_1-V_2)\times c\times 14}{M\times 5/100}\times 100 \tag{1}$$

where V_1 is the titration volume of the tested sample (mL), V_2 is the titration volume of blank (mL), c is the actual concentration of HCl (mol/L), and M is the weight of each sample (g).

2.4. Image preprocessing and feature extraction

To eliminate or minimize effects of some environmental factors, the procedure was conducted on the raw acquired images (R_o) and two reference images (R_b, R_w) by using the following equation:

$$R_a=\frac{R_o-R_b}{R_w-R_b} \tag{2}$$

where R_a and R_o are the corrected and raw spectral images of the sample, respectively; R_b is the dark reference image acquired by completely blocking the lens with an opaque cap; and R_w is the white reference image.

The region of interest (ROI) must be determined from the hyperspectral images because it significantly affects the extraction of spectral features. Image segmentation is important for ROI