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Non-destructively sensing pork's freshness indicator using near infrared multispectral imaging technique

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ABSTRACT

Total volatile basic nitrogen (TVB-N) content is one of core indicators for evaluating pork's freshness. This paper attempted to non-destructively sensing TVB-N content in pork meat using near infrared (NIR) multispectral imaging technique (MSI) with multivariate calibration. First, a MSI system with 3 characteristic wavebands (i.e. 1280 nm, 1440 nm and 1660 nm) was developed for data acquisition. Then, gray level co-occurrence matrix (GLCM) was used for characteristic extraction from multispectral image data. Next, we proposed a novel algorithm for modeling-back propagation artificial neural network (BP-ANN) and adaptive boosting (AdaBoost) algorithm, namely BP-AdaBoost, and we compared it with two commonly used algorithms. Experimental results showed that the BP-AdaBoost algorithm is superior to others with the root mean square error of prediction (RMSEP) = 6.9439 mg/100 g and the correlation coefficient (R) = 0.8325 in the prediction set. This work sufficiently demonstrated that the MSI technique has a high potential in non-destructively sensing pork freshness, and the nonlinear BP-AdaBoost algorithm has a strong performance in solution to a complex data processing.

1. Introduction

China is the largest producer and consumer of pork in the world, and both its output and consumption were more than 50 million tons in 2012 and the quality and safety of pork meat have been an issue of public concern (Wang and Sun, 2013). During the last decades, the consumer demand for pork dramatically grows owing to its high nutritional value and tasty taste. However, pork is highly susceptible to spoilage and contamination. The spoilage of meat occurs in a matter of hours or days if left untreated which results unappetizing, poisonous or infectious meat. Spoilage is caused by practically unavoidable infection and subsequent decomposition of meat by bacteria and fungi, which are borne by the animal itself, by the people handling meat or by their implements (Schirmer and Langsrud, 2010). In the meat industry, to reduce economic losses during processing, as well as to supply high-quality products consistently, quality control procedure must be carried out. Therefore, it is necessary to set out effective methods for reliable objective safety control to guarantee quality and freshness at all stages of the commodity chain.

Meat quality includes many attributes, such as color, texture, pH, tenderness and freshness, among them, freshness is regarded as the most important parameter in assessing meat quality and safety (Kamruzzaman et al., 2012; Leroy et al., 2004; Tao et al., 2012). Meat freshness is a complex indicator including various microbiological, physicochemical and biochemical attributes. The main ingredients of meat like protein, fat and carbohydrates will be decomposed by enzymes and bacteria, producing odors; protein components in pork will be gradually decomposed into hydrogen sulfide, ammonia, ethyl mercaptan, etc., producing some toxic small molecular components including histamine, tyramine, putrescine, and tryptamine; the fat will be decomposed into aldehydes and aldehyde acids; the carbohydrates will be decomposed into alcohols, ketones, aldehydes, hydrocarbons, and carboxylic acid gases (Kong and Ma, 2003). During storage, these substances and other basic nitrogen compounds together make up total volatile basic nitrogen (TVB-N) which is an important index and always used to assess the pork's freshness (Chen et al., 2013; Ozogul and Ozogul, 2009). Traditionally, sensory evaluation, chemical methods including TVB-N evaluation and microbial population evaluation are the key techniques (Zhang et al., 2008). However, these methods are destructive, inefficient and/or time consuming, and consequently impracticable for fast-paced production and on- or at-line application. It is reported that the lack of fast, reliable and nondestructive methods for determining meat characteristics has been one of the main obstacles for the development of quality control in the meat industry (ElMasry et al., 2011). Additionally, the meat

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industry needs rapid analytical methods or tools for quantification of these indicators in order to determine and select suitable processing procedures for their raw material and to predict the shelf of their products. Therefore, it is of great significance for rapid, accurate and nondestructive detection of pork freshness.

In the past decade, imaging technique has been applied for visual evaluation of meat and other food quality and for rapidly identifying quality problems on the processing line by color, shape, size, surface texture (Chmiel et al., 2011; Girolami et al., 2013; Jackman et al., 2011). Near-infrared (NIR) spectroscopy is another increasingly growing technique due to its rapidity, simplicity, and its ability to measure chemical properties or characteristics of food products (Alamprese et al., 2013; Grau et al., 2011; Prevolnik et al., 2010; Prieto et al., 2009). In our previous studies, NIR spectroscopy (Cai et al., 2011) and computer vision (CV) (Huang et al., 2014) were implemented to evaluate the TVB-N content of pork meat. The NIR technique captures the single-point information of the sample purely, and the CV technique just scratches the surface. These restrictions make them not fully reflect the samples. Recently, due to its integration of traditional imaging and spectroscopy, hyperspectral imaging (HSI) technology was widely used for detection of food quality (Barbin et al., 2012; Cheng et al., 2014; Liu et al., 2014b,c). In our previous studies, Huang et al. (2013) predicted the total viable count (TVC) of bacteria in pork meat by HSI technology with a good result; Chen et al. (2013) used HSI evaluating the freshness of salted pork in jelly (SPIJ). However, the researches mentioned above were faced with preprocessing of huge data which will slow the detecting speed. And the cost of HSI system is high, which makes HSI only a laboratory set-up. To satisfy the need of production in food industry, developing a low-cost system is especially important for monitoring of food quality and safety.

In general, the meat spoilage caused by microbes is often accompanied with the changes from the external attributes (color, texture, etc.) and internal attributes (chemical compositions, tissue structure, etc.). In contrast to the conventional NIR spectroscopy that only obtain the internal attributes, MSI and HIS are the emerging platform techniques that integrate traditional imaging and spectroscopy to attain both spatial and spectral information from objects (Huang et al., 2013). Although MSI technique only obtains a few images at a discrete spectral region by positioning a band-pass filter in front of a monochrome camera, we can find the optimum waveband filters by HSI technique to develop a MSI system for practical usage. Compared with the HSI technique, the MSI method, with a low-cost system and simple data, can be more easily used for real-time usage in food field. Liu et al. (2014a) used MSI technique under visible and shortwave near infrared area combined with chemometrics to qualitatively identify transgenic and non-transgenic rice seeds, and achieved a good resolution (up to 100% with LS-SVM model). Panagou et al. (2014) has evaluated the performance of a MSI system combined with linear algorithm in monitoring aerobically packaged beef filet spoilage at different storage temperatures, and the results demonstrated good performance in classifying meat samples with overall correct classification rate for the three quality classes ranging from 91.8% to 80.0% for model calibration and validation, respectively. MSI combined with a linear regression tool – partial least squares regression (PLSR) was reported as a rapid nondestructive technique to determine the aerobic plate count (APC) in cooked pork sausages, which presented a good determination result (Ma et al., 2014). Using MSI technique combined with chemometrics could effectively predict cooked beef tenderness, and the SVM model predicted 91% and STEPWISE predicted 87% average accuracy of beef tender (Sun et al., 2012). However, all the mentioned above researches were in visible and shortwave near infrared area, and most of them did not involve the quantitative analysis.

For the usage of MSI in evaluating food freshness, there is a significant number of classification algorithms used for MSI data processing, and therefore, continuous developments are being made in this sense. At present, PCA, PLS, SVM and ANN are the commonly used pattern recognition algorithms. In this work, a novel efficient nonlinear algorithm BP-AdaBoost was proposed to construct the model for TVB-N content prediction. (Back propagation artificial neural network (BP-ANN) combined with adaptive boosting (AdaBoost) algorithm, namely BP-AdaBoost). AdaBoost, short for Adaptive Boosting, is a machine learning algorithm that is often used in conjunction with many other learning algorithms to improve their performance (Freund and Schapire, 1997). It is adaptive in the sense that subsequent classifiers built are tweaked in favor of those instances misclassified by previous classifier. It is sensitive to noisy data and outliers and has been applied in a lot of applications, including fingerprint classification (Liu, 2010), food identification and quantity estimation (Chen et al., 2012, 2014), image classification (Zhiwen and Hau-San, 2008), etc.

The aim of this work was looking for a non-destructive, rapid, simple and low-cost method for sensing TVB-N content in pork meat. The original contribution of this work was: (1) the MSI system based on the NIR bands filters was developed for real-time detection of TVB-N in pork; (2) BP-AdaBoost, as a novel efficient nonlinear algorithm, was attempted for the solution to complicated MSI data. Accordingly, the specific research work was summarized as follows: (1) acquisition of multispectral images, (2) processing of multispectral images, (3) extraction of characteristic parameters from region of interest (ROI), and (4) comparing BP-AdaBoost, PLS and BP-ANN algorithm for the TVB-N content prediction.

2. Materials and methods

2.1. Preparation of pork samples

Chilled pork's longissimus muscles of the different Landrace (approximately 24 h postmortems) were purchased from a local supermarket and taken to the laboratory in 30 min. Test samples were chopped into 77 pieces of $3 \times 3 \times 1$ cm (length $\times$ width $\times$ thickness) on a sterile surface of the laboratory and the weight of each sample was about 20 ± 0.5 g. Then, all samples were packed with sealing plastic bags and stored at 4 °C during 13 days. Samples were tested in 1st, 3rd, 5th, 9th, 11th and 13th day of storage.

2.2. Determination of TVB-N

TVB-N content in pork meat was measured by a stream distillation method, which can refer to Chinese standard GB/T 5009.44 (2003). All samples for analysis were ground individually using a meat grinder (A-88, Jintan medical instrument plant, China). Ten grams (±0.1 g) of the ground pork was weighted into a beaker, blended with 100 mL distilled water and the mixture stand for 30 min at room temperature and shaken every 10 min. Next, the solution was filtered through the Whatman filter paper (Hangzhou Whatman–Xinhua Filter Paper Co. Ltd., Hangzhou, China). Five millilitres of filtrate was made alkaline with adding 5 mL of $10\ g \cdot L^{-1}$ Magnesia (MgO) and distilled for 5 min using a Kjeldahl distillation unit (ZLQ03, East China Glass Co. Ltd., China). The distilled was collected in an Erlenmeyer flask containing 10 mL of $20\ g \cdot L^{-1}$ boric acid, and then titrated with $0.01\ mol \cdot L^{-1}$ HCl. The amount of TVB-N was calculated using the following equation. The result stated for each sample is the mean value of two measurements:

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