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Predicting intramuscular fat content of pork using hyperspectral imaging

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ABSTRACT

Intramuscular fat (IMF) content is an important quality trait of pork. It influences taste, juiciness and tenderness of the meat. The aim of this study was to develop an objective, rapid, and non-destructive method for predicting the IMF content of pork using hyperspectral imaging technology. Critical wavelengths were selected using correlation analysis based on the spectral profiles of pork samples. The visual IMF flecks on both sides of pork chops were extracted using the wide line detector at the selected critical wavelengths. The proportion of IMF fleck areas (PFA) at critical wavelengths was used for modeling to predict the IMF content of pork. Both stepwise procedures and partial least squares (PLS) analysis were employed to establish the prediction models. Three different multilinear models were obtained using the stepwise procedure with different first entry variable of the initial model. A 3-component PLS model was developed for prediction of the IMF content. The PLS model outperformed the three multilinear models. The coefficients of determination (R^2) of the PLS model on the calibration set and validation set were 0.94 and 0.97, respectively, and the adjusted R^2 were 0.92 and 0.93, respectively. The prediction results of mutilinear models and PLS models indicated the potentials of using hyperspectral imaging to predict the IMF content of pork.

1. Introduction

Intramuscular fat (IMF) corresponds to the amount of fat found between muscle fiber bundles within muscles. The amount of IMF, i.e. IMF content, varies between species, breeds and muscle types. IMF content plays an important role in various quality traits of pork. It is generally accepted that a higher IMF content has a positive effect on sensory quality traits of pork, for example, juiciness, tenderness, and flavor. Since it is strongly related to carcass quality, IMF content is also a useful tool to make genetic improvement in selection programs for carcass quality in the pork industry.

IMF content is normally determined by chemical extraction of lipid from muscle samples (Folch et al., 1957). Chemical extraction is time-consuming, labor-intensive and destructive, which makes it not suitable for industrial application. In the pork industry, another quality trait, i.e. the marbling score, is widely used to estimate the IMF content of muscles. Marbling refers to the visible IMF of muscles. Marbling scores are visually assessed by experienced assessors by comparing marbling levels of meat with a standardized chart system (NPB, 2002). However, visual and subjective measurement of marbling scores can be difficult and has poor repeatability of results. This makes the estimation of IMF content unreliable. Therefore, an objective, rapid, accurate and non-destructive measurement for the IMF content would be an asset for the pork industry.

Recent research efforts have shown high potential of hyperspectral imaging (HSI) in the development of objective, rapid, and non-destructive systems for assessment of food quality. Hyperspectral imaging is an emerging, cutting-edge and non-destructive analytical technology that combines spectroscopy and digital imagery to simultaneously acquire both spectral and spatial information from an object. A hyperspectral image, also called '*hypercube*', is a three-dimensional image with two spatial dimensions and one spectral dimension (Qiao et al., 2007a,b), which contains enormous information about the analyzed object. The combination of spectral and spatial information makes hyperspectral imaging able to ascertain minor and/or subtle physical and chemical properties in an object. The advantages of hyperspectral imaging indicate that the technology has a promising future for food quality inspections. With respect to pork, hyperspectral imaging has been successfully applied for classification of pork qualities (Qiao et al., 2007a; Liu et al., 2010; Barbin et al., 2012a) and for prediction of quality traits such as color, pH, and drip loss (Qiao et al., 2007b; Barbin et al., 2012b). Hyperspectral imaging was also

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Table 1
Statistics of pork samples.

	Mean	Max	Min	Std
Chemical IMF content	2.06	3.21	0.61	0.79

applied for assessment of pork marbling scores based on the image texture index measured by angular second moment (ASM) (Qiao et al., 2007a). The results showed that the sorted results using ASM were higher than that obtained by experienced assessors with an error around 1.0.

In the very recent publications, an advanced image processing method, the wide line detector (WLD), was introduced to detect marblings of intact pork muscles from digital color pictures (Liu et al., 2012; Huang et al., 2013). The high prediction results at all the three RGB channels indicated the ability of the wide line detector to extract useful image features for prediction of marbling scores, i.e. the amount of the visible IMF of muscles. This strongly suggested the potential of using the WLD to predict the IMF content of pork.

This paper aimed to develop advanced hyperspectral imaging techniques to predict the IMF content of pork in a non-destructive, rapid and accurate way. The specific objectives were to extract spectral features and identify the critical wavelengths for prediction of the IMF content; to detect the IMF flecks on both sides of pork chops at the critical wavelengths using the wide line detector; and to develop and validate different regression models based on detected IMF flecks to predict the IMF content of pork.

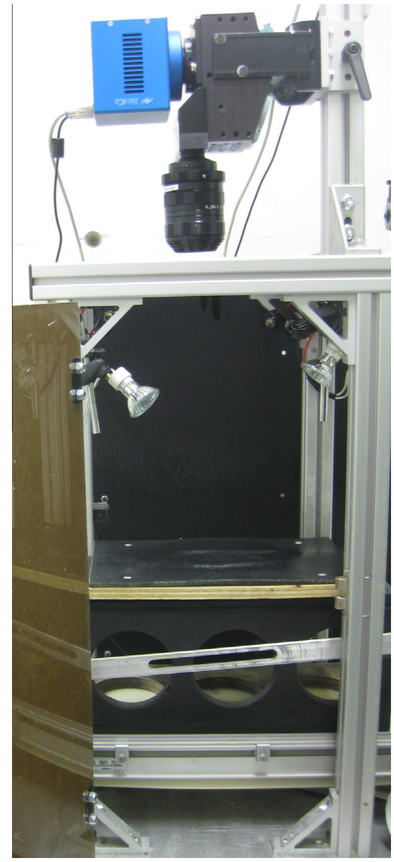

Fig. 1. The near infrared hyperspectral imaging system used in the study.

2. Materials and methods

2.1. Pork samples

Four packages of pork loin center chops were bought from three different grocery stores in Montreal, Quebec, Canada. A total of 20 pork samples with thickness between 1 and 1.5 cm were used for predicting intramuscular fat content of pork.

2.2. Near infrared hyperspectral imaging system and image acquisition

A laboratory near infrared (NIR) hyperspectral imaging (HSI) system was set up to collect the hyperspectral images of the pork samples. The NIR-HSI system consisted of an InGaAs camera mounted with a line-scan spectrograph (Headwall photonics, USA, 900–1700 nm), two halogen lamps (JDR-C GU10, 120 V, 50 W) placed an angle of 45° to illuminate the camera's field of view, a moving conveyer driven by a stepping motor with a user-defined speed (MDIP22314, Intelligent motion system Inc., USA), an anodized aluminum enclosure, and a PC, as shown in Fig. 1.

Each pork sample was placed on a dark panel and double-side-imaged line by line using the NIR-HSI system with an optimal speed. The obtained hypercube (hyperspectral image with the BIL format) included 167 image planes over the range of wavelengths 900–1700 nm with the resolution of 4.8 nm. A total of 40 hypercubes were obtained for this study.

2.3. Intramuscular fat content analysis

After imaging, all pork samples were carefully trimmed to remove peripheral and intermuscular fat as well as the connective tissue and surrounding muscles. Samples were freeze-dried and ground in a coffee grinder (Bodum 5678-57; C-Mill, Bodum Inc., New York, NY, USA). A ground meat sample of known weight was used for determining the intramuscular fat (IMF) content in duplicate with petroleum ether extraction using a Solvent Extraction Unit SER 148/6 (Velp Scientifica, Usmate, Italy), in accordance with Official Method 960.39 (AOAC, 2000). IMF content was determined as the ratio of the mass of extracted fat and the mass of the sample before freezing. The statistics of IMF content for all pork samples are listed in Table 1.

2.4. Image preprocessing

All the acquired hypercubes were processed and analyzed using MATLAB 7.13.0.564 (The MathWorks, Inc., Mass., USA). Each hypercube was corrected from the dark current of the camera prior to segmenting the region of interest (ROI) of each sample. To correct the spectral images, a dark image *B* and a white image *W* were obtained by covering the lens with a cap, and by taking an image from a standard white reference (Spectralon, Labsphere,

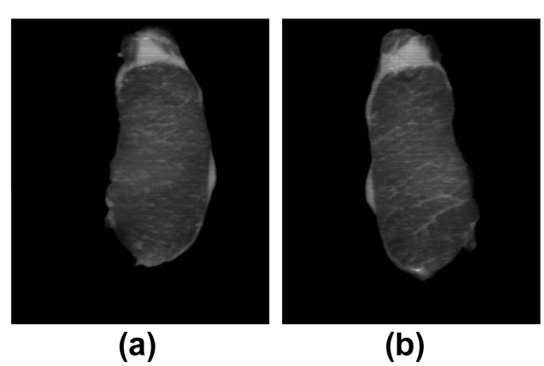

Fig. 2. Corrected image planes of (a) Side 1 and (b) Side 2 of a pork sample at 1076 nm.