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DISCRIMINATION OF LAMB MUSCLES BY NIR HYPERSPECTRAL IMAGING

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ABSTRACT Hyperspectral imaging has been emerged to combine imaging and spectroscopy techniques in a single system to acquire both spatial and spectral information simultaneously. It is considered one of the most efficient techniques and advanced non-destructive technologies for the estimation of quality attributes of different food products. In this study a near-infrared (NIR) hyperspectral imaging system (900-1800 nm) was developed for discriminating lamb muscles of Charollais breed. Muscles from *Semitendinosus* (ST), *Semimembranosus* (SM), M. *Longissimus dorsi* (LD) and *Psoas Major* (PM) at 2-day post-mortem were tested in this study. Principal components analysis (PCA) was used for dimensionality reduction, wavelength selection and to aid in visualizing the hyperspectral data. The results showed that hyperspectral imaging has a great capability for discrimination between lamb muscles.

Keywords: hyperspectral imaging, discrimination, lamb muscle, PCA, *Charollais*.

INTRODUCTION Hyperspectral imaging is an emerging, non-contact analytical technology that combines both imaging and spectroscopy to acquire both spatial and spectral information from an object. A hyperspectral image consists of several congruent images representing intensities at different wavelength bands. Each pixel in a hyperspectral image represents a spectrum of that specific point (Williams *et al.,* 2009). The information from one image forms a three- dimensional "hypercube" which can be analyzed to determine physical and chemical features of an object. Because of the combined features of imaging and spectroscopy, hyperspectral imaging can be used to detect physical and geometric characteristics such as colour, size, shape and texture through image feature extraction as well as chemical composition such as water, fat, protein, and other hydrogen-bonded constituents through spectral analysis (ElMasry *et al.,* 2008 and Qiao *et al.,* 2007).

Recently, several researches have been focused on using hyperspectral imaging technique to evaluate the quality of fruits (Kim *et al.,* 2002a; ElMasry *et al.,* 2009; Mehl *et al.,* 2004), vegetables (Cheng *et al.,* 2004, Liu *et al.,* 2006; Ariana *et al.,* 2006) and meat (Qiao *et al.,* 2007; Naganathan *et al.* 2008; Chao *et al.,* 2001, Park *et al.,* 2002; Windham *et al.*, 2005). There are ample potentials to work on hyperspectral imaging systems to extract the spectral information for the evaluation of meat quality. However, hyperspectral technology cannot be directly implemented as it is in an online system for quality evaluation because of the extensive time needed for image acquisition and subsequent analysis (Mehl *et al.*, 2002). However, hyperspectral imaging can be a very useful research tool for determining key wavelengths, which later can be implemented in a multispectral imaging system. Many studies have been carried out in recent two decades regarding lamb meat characteristics. However, up to date, no research has been conducted for the quality evaluation of lamb meat by hyperspectral imaging. As a first attempt, the potential of NIR hyperspectral imaging technique was evaluated for the discrimination of lamb muscles.

MATERIALS AND METHODS

Sample preparation

Lamb samples for this study were collected from Ashtown Food Research Centre (AFRC), Teagasc, Dublin 15, Ireland. Ten animals of *Charollais* breed were slaughtered and dressed according to Current EU regulations. After slaughtering, carcasses were chilled at 4^0C for 24 h, and steaks of 1-inch thick from *Semitendinosus* (ST), *Semimembranosus* (SM), M. *Longissimus dorsi (*LD*) and Psoas Major* (PM*)* were cut and then individually vacuum packed. The samples were shipped to the laboratory of Biosystems Engineering Department, University College Dublin in an ice box and kept at 4^0C for 2 days post-mortem before image acquisition.

NIR hyperspectral imaging system

The schematic representation of NIR hyperspectral imaging components is shown in Fig 1. The NIR hyperspectral imaging system consists of a spectrograph (ImSpector N17E, Specim, finland), a camera (XEVA 992, XC 130 XenICs, Belgium), an illuminator (Lowel V- light^{TM},NY, USA), a conveyer, a motor and a PC with image acquisition software.

Reflectance calibration

The recorded raw hyperspectral image of the sample was corrected for absolute reflectance and calculated using the following equation (ElMasry *et al.*, 2009):

$$R = \frac{R_0 - D}{W - D} \times 100$$

Where R_0 is the raw hyperspectral image of the lamb sample, D is the dark current image (approximately with 0% reflection) and W is the white reference image taken from a standard white reference board (approximately 99% reflectance). The spectral data for processing was limited to 910–1700 nm with 237 spectral bands due to the high noise level beyond this range.

Image segmentation

All images are processed and analyzed individually using Environment for Visualizing Images (ENVI) software (Research Systems Inc., Boulder, CO, USA). For separating the whole sample (lean and fat), subtraction operation was applied between images of high and low contrast and then segmented with threshold values at 0.09 and 1. For isolating only fat portions from the lean part, segmentation was performed for the detection of fat to this image between threshold value of 0.055 and 1. Finally, the lean portion was isolated by subtracting the last segmented image (containing only fat portion) from the first segmented image (containing both lean and fat portions) to produce a lean part in a black background. The isolated lean portion was then treated as ROI to be used for extracting spectral data from each muscle.

RESULTS AND DISCUSSION

Spectral features of the muscles

The average reflectance spectra for each lamb muscle in the spectral range of 910-1700 nm are shown in Fig 2. Although the spectral curves of the muscles show a similar trend, the spectral profiles are substantially distinguished from each other. PM and ST muscles showed higher reflectance values than those of LD and SM. The difference in reflectance values among muscles are attributed to the different compositions and characteristics of the tested muscles.

Discrimination of spectra by Principal Components Analysis (PCA)

Principal Components Analysis (PCA) was experienced on all spectra of all tested muscles to reduce the dimensionality and to examine qualitative discrimination in the spectra between the muscles. Each principal component (PC) explains a certain portion of the overall spectral information. Figure 3 shows the score plot of PC1 vs. PC3, which reveals the feasibility of discrimination between the muscles. However, this plot only demonstrates the qualitative difference without referring to the chemical composition assessed quantitatively by any traditional chemical assessment methods. The first five PCs account for 99.68% of the total variation of the reflectance data and these five PCs were used as inputs for LDA classification. The results indicated that the four tested lamb muscles were classified with accuracy of 92% indication the high potentiality of NIR hyperspectral imaging technique for classification purposes.

Determination of key wavelengths

The loadings of PCA were used for selecting key wavelengths. The loadings of the first three principle components in the entire spectral range are presented in Fig 4. The wavelengths corresponding to the highest absolute peaks and valleys were selected as key wavelengths. Four most important wavelengths (980, 1141, 1208 and 1441 nm) were selected by using loading of PCA for the classification purposes. These important wavelengths can be used for lamb muscle classification using multispectral imaging instead of the whole spectral range.

CONCLUSION A NIR hyperspectral imaging system was developed to discriminate lamb muscles with the extracted reflectance data as input. The results suggested that NIR hyperspectral imaging can be used as a non-destructive tool for the discrimination of lamb muscles. Using NIR hyperspectral imaging, it is possible to classify lamb muscles with overall accuracy of 92%. More research is needed to incorporate more samples as well as different muscles to improve the accuracy and robustness of the discrimination.

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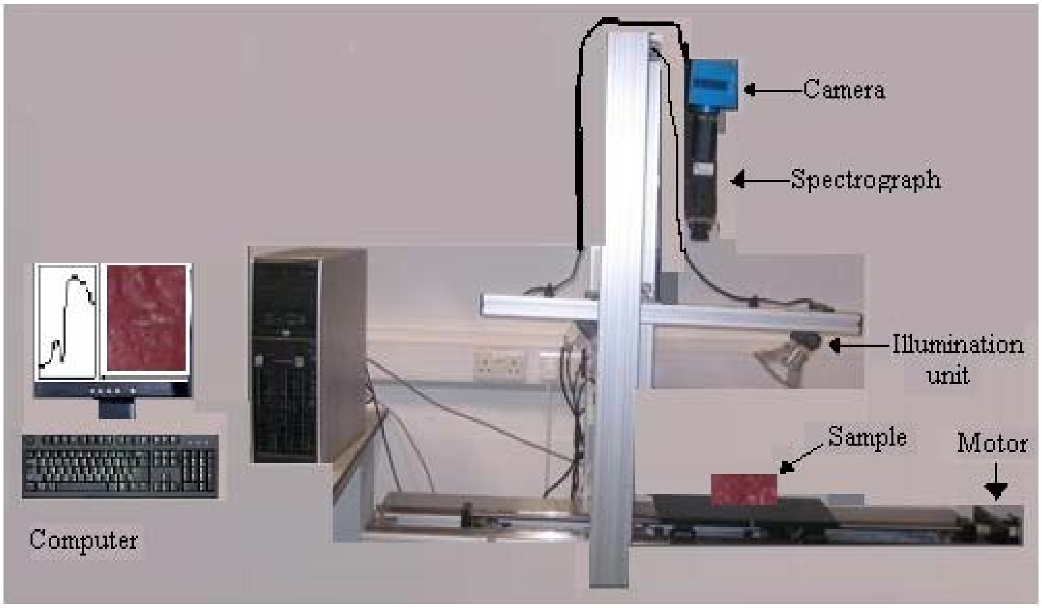

Figure 1: A laboratory NIR hyperspectral imaging system.

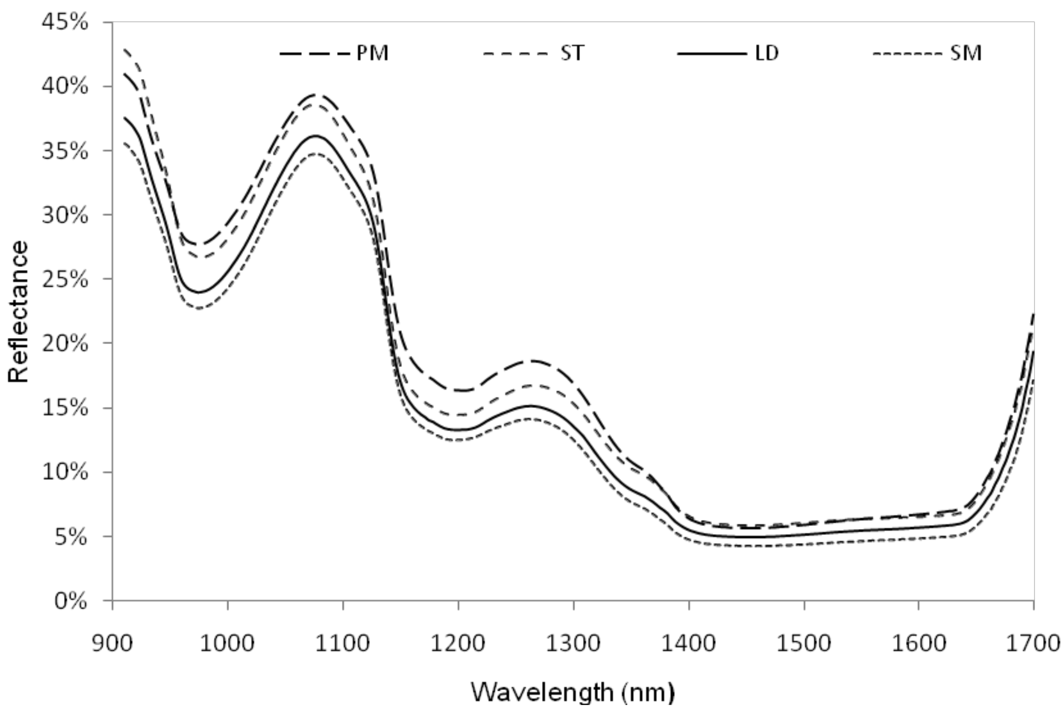

Figure 2: NIR average reflectance spectra of the tested muscles.

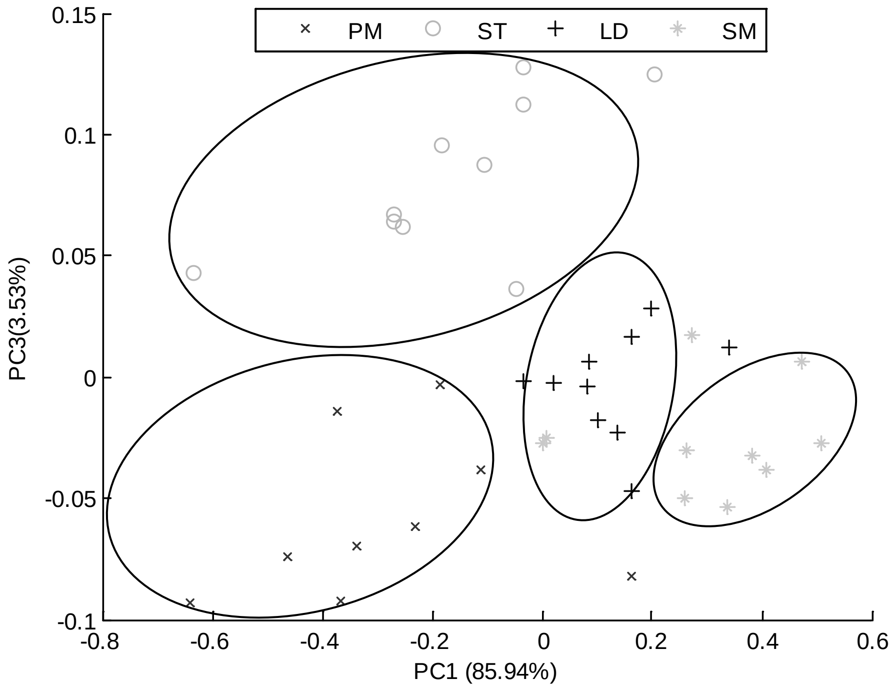

Figure 3: Discrimination plot of PCA with 4 muscles at 910-1700 nm

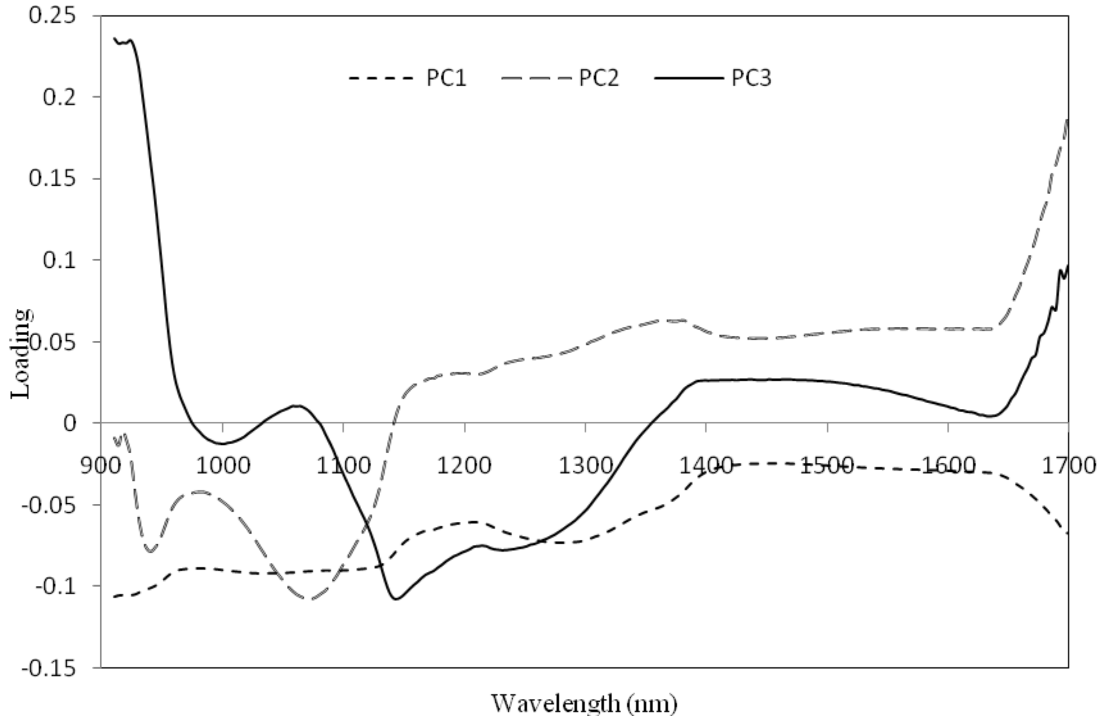

Figure 4: Loading spectra of the first three PCs for wavelengths selection.