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USE OF HYPERSPECTRAL IMAGING FOR THE QUALITY CLASSIFICATION OF COOKED TURKEY HAMS

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ABSTRACT This study was carried out to develop a hyperspectral imaging system in the near infrared (NIR) region (900-1700 nm) to evaluate the quality of cooked turkey hams. Different qualities of turkey hams were studied based on their chemical ingredients and processing parameters used during processing. Hyperspectral images were acquired for ham slices originated from each quality class and then their spectral data was extracted. Spectral data was analyzed using Principal component analysis (PCA) to reduce the high dimensionality of the data and for selecting some important wavelengths. It is seen that from 241 wavelengths, only five wavelengths (980, 1061, 1141, 1215 and 1326 nm) was considered to be the optimum wavelengths for the classification and characterization of turkey hams. The data analysis showed that it is possible to separate different quality turkey hams with few numbers of wavelengths on the basis of their chemical composition. Linear Discriminant Analysis (LDA) showed that the best classification accuracy was 88.57%. The result revealed the potential of NIR hyperspectral imaging as an objective, rapid and non-destructive method for the authentication and classification of cooked turkey ham slices.

Keywords: Hyperspectral imaging, NIR, turkey ham, classification.

INTRODUCTION

The ham processing industry needs non-invasive, efficient and effective technologies for quality assessment of ham products. The quality of meat products varies greatly, and meat processors, especially turkey meat processors, need more scientific data to deliver formulated products to meet consumer requirements. Producers and processors undergo economic losses when meat quality is not accurately judged. In practice, the quality of turkey ham is normally assessed subjectively by an experienced grader and the outcome of this subjective grading may vary with different inspectors. Therefore, a rapid, objective and non-destructive technique is needed for fast classification and characterization of turkey ham quality, desired by the meat industry.

Hyperspectral imaging techniques provide spatial information, as regular imaging systems, along with spectral information for each pixel in an image. Due to the advantages of non-destructive, free of chemical preparation and fast inspection speed, hyperspectral imaging has been studied extensively for determining properties of fruits (Lu, 2003; Lu *et al*., 1999; Mehl *et al*., 2004), vegetables (Ariana *et al*., 2006; Cheng *et al*., 2004; Polder *et al*., 2002) and meat (Chan *et al.*, 2002; Park et al., 2004; Barlocco, *et al*., 2006; Savenije, *et al.*, 2006). The current hyperspectral imaging systems cannot directly be implemented in an online system for sorting and classification of agricultural product because of the extensive time required for image acquisition and subsequent analysis (ElMasry *et al*., 2008). However, hyperspectral imaging can be a very useful research tool for determining important spectral bands, which later can be implemented in a multispectral imaging system. These bands can be obtained through different analysis methods such as spectral difference and principal component analysis (Lu, 2003; Mehl *et al*., 2004; Liu and Ying, 2005). There are various contributions on the usefulness of near infrared spectroscopy (NIRS) to predict meat quality attributes, such as drip loss, pH, water holding capacity and tenderness in fresh as well as in processed meat. Few researches have been carried out to evaluate the quality of hams. Garci´a-Rey *et al.* (2005) investigated the feasibility of VIS/NIR spectroscopy for the classification of dry-cured hams as a function of their texture and colour. Sheridan *et al.* (2006) measured the colour stability of pre-packaged sliced hams. Sensory characteristics of dry-cured ham have been evaluated by Ortiz *et al.* (2006) using visible and near infrared spectroscopy. However, to our knowledge, no research endeavours have been reported in respect to characterizing turkey hams into different quality groups using hyperspectral imaging systems. **The objective of this study is to develop a hyperspectral imaging system in the spectral region between 900 and 1700 nm for the classification and characterization of turkey hams.**

MATERIALS AND METHODS

Preparation of turkey ham samples Turkey hams with four quality classes based on different moisture content and different processing parameters were manufactured in Ashtown Food Research Centre (AFRC), Dublin, Ireland. All hams were made by using whole butterfly turkey breast with the injection of different percentages of brine solutions (wet curing by injection) in addition to other ingredients and processing parameters**.** The four classes of hams were identified as: Block1 (B1), Block2 (B2), Block3 (B3) and Block4 (B4), respectively. All samples were formed after tumbling, netting, vacuum shrink packaging, pot moulded and steam cooking at 80^0 C to a core temperature of 72°C. All cooked turkey blocks were then chilled in pot moulds at 4°C till the time of analysis. The actual average values of moisture content in the injected brine were 83.7%, 89.2%, 91.08% and 92.24%, for B1, B2, B3 and B4 respectively. All evaluated ham slices (four qualities, on the basis of moisture content) possess a discoloured or pale appearance with a large degree of colour uniformity making difficult for visual characterization or description. Images were acquired immediately after slicing the hams to 10-mm-thick slices.

Hyperspectral imaging system A laboratory NIR hyperspectral imaging system (900-1700 nm) as shown in Figure 1 was developed to acquire hyperspectral images for the turkey ham slices. The hyperspectral imaging system consists of a spectrograph (ImSpector N17E, Specim, spectral imaging Ltd, Oulu, Finland), a high performance camera (Xeva 992, XC 130 Xenics, Belgium), illumination source (V320, 500W, Lowel V-lightTM,NY, USA), a conveyer translation stage (GPL-DZTSA-1000-X, Zolix Instrument Co. Ltd, China) and a computer supported with image acquisition software (SpectralCube, Spectral Imaging Ltd., Finland). The subsequent calibration, analysis and extracting spectral data from the image were performed with software ENVI 4.6.1 (ITT visual information solutions, Boulder, CO, USA). The actual optical sensitivity of this system ranges from 900 to 1800 nm but the best working sensitivity was nearly from 910 to 1700 nm to avoid low signal-to-noise ratio.

Image acquisition and pre-processing During image acquisition, ham slices were conveyed one at a time to the field of view (FOV) of the camera with an optimized velocity of 2.7 cm/s. Upon entering the FOV, a hyperspectral image of the sample was taken and the image was sent to the computer through a USB port for storage. The images were calibrated due to dark current effect of camera, and to obtain a relative reflectance using equation 1.

$$I = \frac{I_0 - D}{W - D} \qquad (1)$$

where I is the relative-reflectance corrected image; I_0 is the original raw image; D is the dark image (with 0% reflectance) obtained by covering the lens with an opaque cap and W is the white reference image (white Teflon tile with ~ 100% reflectance).

Segmentation of images The images were segmented to isolate the ham portions in a clear background with the aid of ENVI software (ITT visual information solutions, Boulder, CO, USA). Image at wavelength of 941 nm was subtracted from the image at wavelength of 1416 nm and then the resulting image is segmented with a minimum threshold of 0.17 and a maximum threshold of 1.0 to get the whole object (turkey hams with its fat covering layer) in a black background. Similarly, subtracting band at 1215 nm from band at 1269 nm was conducted followed by simple thresholding to isolate the fat part from the ham part. After masking the whole spectral image with this final segmented image, the target object (only turkey ham without fat layer) was obtained in a black background. After segmentation, each image (images containing only turkey and images containing only fat) was used for the extraction of spectral information.

Data analysis The spectral data were extracted from each slice of different ham qualities and analysed using principal component analysis (PCA) and linear discriminant analysis (LDA) to reduce the dimensionality and to classify the samples.

RESULTS AND DISCUSSION

Spectral Reflectance The mean spectra in the range of 910-1700 nm of the four tested blocks of turkey ham qualities are shown in Figure 2. The overall features of the average spectra of hams showed that there are noteworthy differences among ham blocks in terms of their spectral attributes indicating differences in their chemical compositions. The absorption bands observed at 980 and at 1460 nm ascribed to O–H stretch second overtones are mainly related to water content of the samples. Water is the main component of turkey slices ranging for 83.7% to 92.24%. Around 1200 nm, absorption bands are related to C–H stretch second overtone (Cozzolino and Murray, 2004).

As seen in Figure 2, the B1 (the lowest moisture content block of 83.7%) differs to a large extent from the other three ham quality blocks in its reflectance pattern. This indicates that a two-stage separation procedure may be considered indicating the facility of discriminating this black from the other quality blocks of high moisture contents. As illustrated in Figure 2, the blocks containing higher moisture contents (B2, B3 and B4) possessed lower reflectance value throughout the whole spectrum compared with the first block. At 1650 nm to the end of the spectrum, the reflectance values of the high moisture blocks are higher than those of the first block but this difference is not considered to be noticeable. The difference among blocks of high moisture content could not be noticed by visual inspection of the spectral curve, but it could be inferred by multivariate analysis of their spectral data.

Selection of Effective Wavelengths Principal component analysis (PCA) was carried out first using the all spectral data extracted from all turkey ham quality blocks, and the loadings of PCA results were plotted against the wavelengths (Figure 3) to select the most important wavelengths. From the loadings versus wavelengths plots, five wavelengths (980, 1061, 1141, 1215 and 1326 nm) were selected as the most effective wavelengths which can be used to discriminate between different blocks of turkey ham qualities.

PCA using effective wavelengths Once the important wavelengths were selected, the PCA was carried out again but this time by using spectral values at those selected wavelengths only. As shown in Figure 4a, it is easy to classify the four blocks of turkey into two groups (low and high moisture groups) using their reflectance values at the selected five wavelengths (Figure 4a) considering the first block as the low moisture group and the other three blocks as the high moisture group. Also, it is evident from Figure 4a that both low and high moisture ham classes could be differentiated easily from fat spectra because they have distinct spectral signatures. However, these selected five wavelengths were not able to separate ham blocks to more than two moisture classes as shown in Figure 4b. By using only two wavelengths (980 and 1140 nm), B1 and B2 were able to be differentiated and separated as distinct groups as low and intermediate moisture groups respectively (Figure 4c). However, B3 and B4 are overlapped with each other treating as a third group of a high moisture class (Figure 4c). This result implies that turkey hams can be classified on the basis of their moisture into three distinct classes (low, intermediate and high).

Discriminant Classification Linear Discriminant Analysis (LDA) was used to classify the different quality turkey hams. Table 2 summarizes the classification performance using different sets of wavelengths based on LDA as the selection criterion. Results show that classification performance was 22.86% when all the wavelengths (241 wavelengths) were taken into account as classification variables considering four quality classes of hams. The classification rates were enhanced to 67.14% and 88.57%, when only two (980 and 1141 nm) and five (980, 1061, 1141, 1215 and 1326 nm) wavelengths were considered, respectively. LDA showed that during the classification with five wavelengths, few samples from B3 and B4 overlapped with each other (Figure 4b). While two wavelengths are considered, it is seen that B2, B3 and B4 differentiates each other with few overlapping among the groups. However, B1 is completely classified from the other three quality groups (Figure 4b). For practical applications, however, the importance of the best selected wavelengths lies in the high sensitivity to characterize and represent the appearance variability of turkey hams which are made with similar formulations and processing conditions, but being different in the level of brine injections and additives. This is relevant in the ham industry since definition of quality based on simple quantitative parameters can be used for determining a quality tolerance range during processing.

Table 2: Summary of classification performance for turkey hams using linear discriminant analysis.

No. of Wavelengths	Groups	Classification
241	4	22.86%
5	4	88.57%
2	4	67.14%
241	3	75.71%
5	3	84.29%
2	3	85.71%

CONCLUSION A hyperspectral imaging system in the near infrared (NIR) region (900-1700 nm) was developed to evaluate the quality of cooked turkey hams of different quality grades. The result showed that the best classification accuracy was 88.57% indicating that the potential of NIR hyperspectral imaging as an objective, rapid and non-destructive method for the authentication and classification of cooked turkey ham slices.

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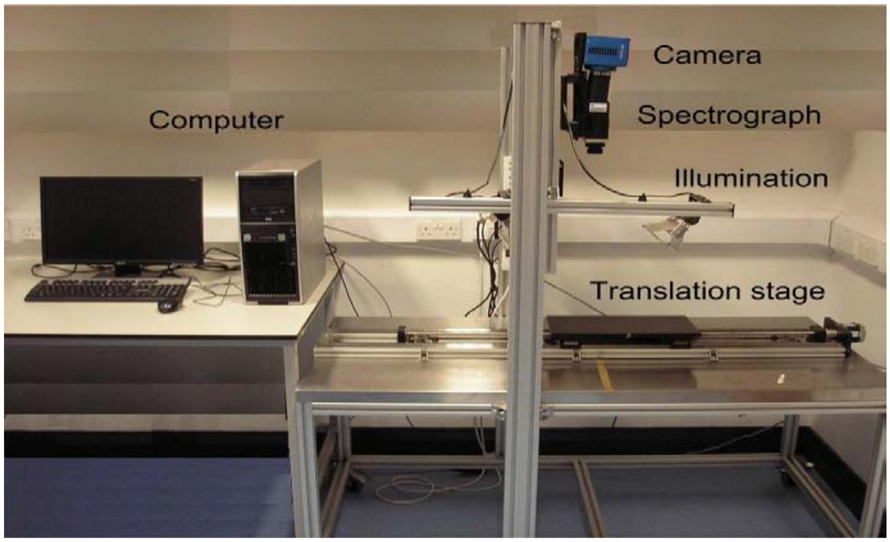

Figure 1 NIR hyperspectral imaging system.

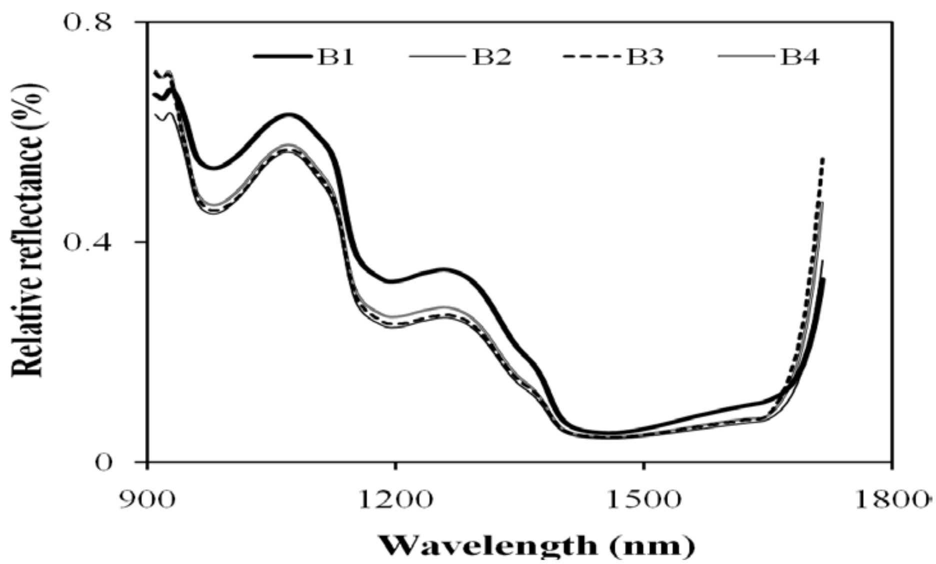

Figure 2 Spectral features of turkey hams. B1: Turkey ham block of 83.7% moisture content, B2: Turkey ham block of 89.2% moisture content, B3: Turkey ham block of 91.08% moisture content, B4: Turkey ham block of 92.24% moisture content.

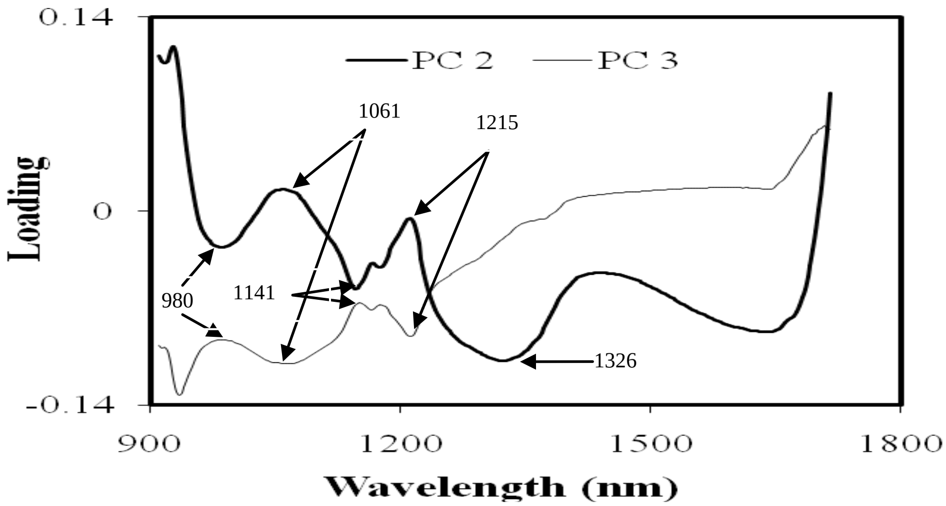

Figure 3 Identification of effective wavelengths from of loading-wavelength plot.

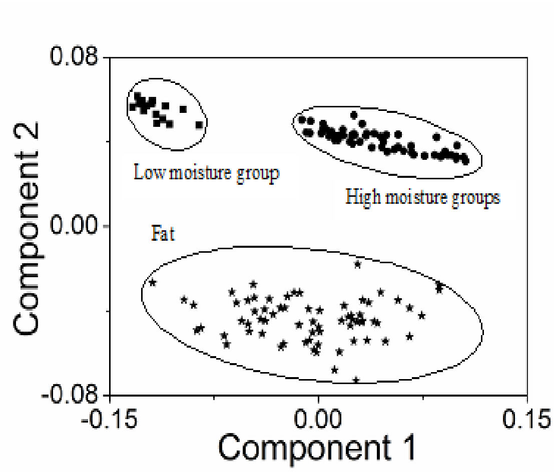

Figure 4 (a) PCA with five wavelengths for ham quality blocks and fat.

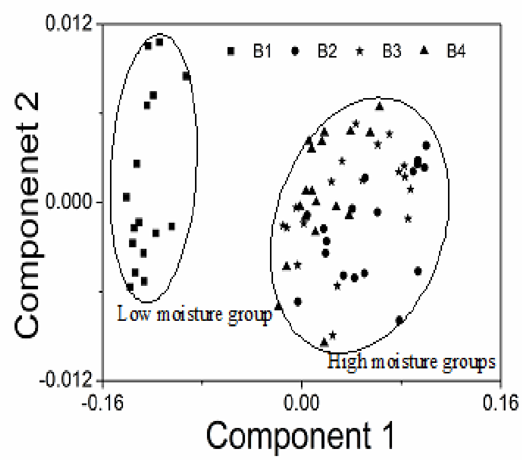

Figure 4 (b) PCA with five wavelengths for ham quality blocks.

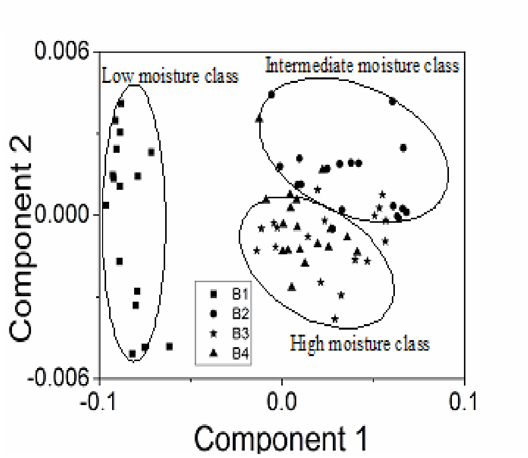

Figure 4 (c) PCA with two wavelengths for ham quality blocks.