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Predicting quality and sensory attributes of pork using near-infrared hyperspectral imaging

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ABSTRACT

Many subjective assessment methods for fresh meat quality are still widely used in the meat industry, making the development of an objective and non-destructive technique for assessing meat quality traits a vital need. In this study, a hyperspectral imaging technique was investigated for objective determination of pork quality attributes. Hyperspectral images in the near infrared region (900–1700 nm) were acquired for pork samples from the *longissimus dorsi* muscle, and the representative spectral information was extracted from the loin eye area. Several mathematical pre-treatments including first and second derivatives, standard normal variate (SNV) and multiplicative scatter correction (MSC) were applied to examine the influence of spectral variations in predicting pork quality characteristics. Spectral information was used for predicting color features (*L*, *a*, *b*, *chroma and hue angle*), drip loss, pH and sensory characteristics by partial least-squares regression (PLS-R) models. Independent sets of feature-related wavelengths were selected for predicting each quality attribute. The results showed that color reflectance (*L*), pH and drip loss of pork meat could be predicted with determination coefficients (R^2_{CV}) of 0.93, 0.87 and 0.83, respectively. The regression coefficients from the PLS-R models at the selected optimal wavelengths were applied in a pixel-wise manner to convert spectral images to prediction maps that display the distribution of attributes within the sample. Results indicated that this technique is a potential tool for rapid assessment of pork quality.

1. Introduction

"Lean quality" in fresh pork refers to a wide range of factors, but mainly focuses on muscle color, pH and water-holding capacity (WHC). These factors are the major quality attributes that directly affect raw product attractiveness to potential customers and influence technological properties for processed products. Color and water-holding capacity of pork are the most important characteristics for the consumer [1,2], as they have an effect on the appearance of cuts in the retail display. Color has been shown to be indicative of beef tenderness, as trained panelists have found darker pork chops to be more tender and juicy than lighter colored pork chops [1]. Exudation depends on the muscle temperature and rigor development, which affect the sarcomeres length during slaughtering and post-mortem processing. The water holding capacity of pork is commonly expressed as the drip loss, which denotes the juice essentially consisting of water and proteins that can be expeled from a piece of meat without mechanical force other than gravity [2]. Besides, the water content determines to a large extent the juiciness of meat and thereby the eating quality [3–5].

There is still no general standard procedure for measuring exudation, and most of the used methods are destructive and time-consuming. Hence, water-holding capacity is often indirectly estimated by means of different measurements such as meat color or pH value; however these measurements are not always well correlated [6]. The rate and extent of the pH fall after slaughter can influence the degree of protein denaturation and affect fresh pork quality attributes such as color and water-holding capacity [7–10].

Fresh pork is classified into three main quality grades: RFN (reddish-pink, firm and non-exudative), PSE (pale, soft and exudative) and DFD (dark, firm and dry). In addition, there are recently some other described quality grades which represent various combinations of color, texture and drip loss, such as: RSE (red, soft and exudative), and PFN (pale, firm and non-exudative). RSE pork is a class of pork with standard color but with a soft texture and an exudative constitution similar to PSE meat, while PFN pork has normal structure but with a pale color [11,12]. Predicting pork quality attributes independently could hold a great advantage for pork classification. In practice, the quality of pork is normally assessed subjectively by an experienced grader, making it a difficult task when several combinations of characteristics must be evaluated.

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Furthermore, individual determination of the quality attributes could be more useful for meat retailers, as a recent investigation has shown that one third of the loins with above-average brightness were only slightly exudative, and one third of the loins with higher than average exudation were red rather than pale [2]. Early prediction of quality attributes in the meat industry would be convenient for slaughterhouses and further processors, as it would allow the assortment and selection for specific destinations.

Overall acceptance of pork is associated to several sensory attributes such as tenderness, flavor and juiciness, and how these attributes are influenced by technological features. Instrumental measurements of tenderness are rather simplistic in comparison to the intricate set of interactions that occur in the mouth. Hence, there are some concerns regarding the level of correlation between instrumental measurements and sensory responses of meat texture [13,14]. Experienced panelists are usually trained to score the specific attributes of eating quality. Sensory quality of the muscle *longissimus dorsi* is of special interest, because this part of the carcass is usually destined for fresh consumption [15]. Therefore, the meat industry could benefit from a fast and non-destructive method for identification and quantification of pork quality features.

Previous studies have emphasized the capability of spectroscopic methods to predict pork attributes [16–18]. Spectroscopic systems usually have very small spatial field of view; therefore it can be easily affected by the selection of region-of-interest (ROI) to be analyzed. Several attempts have been made to classify pork meat from different grades with relative success. Results using a few selected wavelengths instead of the whole visible spectral range showed that a hyperspectral system could predict drip loss, pH, and color of pork meat with correlation coefficients of 0.77, 0.55 and 0.86, respectively [19]. These results are encouraging, and could be improved in order to be confidently utilized by the meat industry for practical applications. In addition, studies have come short when these grades involve variations in single attributes. Variations of some parameters can occur within a muscle or meat chop, and visualizing this variation can aid to sort samples based on its quality. The near-infrared spectral region (800–2500 nm) consists of overtones and combination bands of the molecular absorptions found in this range, and can be useful for applications where multi-component molecular vibration analysis is required in the presence of intrusive substances [20–23]. Therefore, it is advantageous to use near-infrared imaging, which renders a more detailed discrimination compared to spectral information in the visible range.

The main objective of the present study was to investigate the potential of using NIR hyperspectral reflectance imaging technique as a fast and non-invasive method to predict pork quality attributes and trained sensory panel palatability judgments. Specific objectives were to (1) establish a satisfactory approach to extract spectral data from hyperspectral images of pork samples acquired in the NIR range (900–1700 nm), (2) study whether spectral pre-processing methods can improve robustness of the prediction models, (3) build robust PLS-R calibration models to quantitatively relate spectral information and quality attributes, (4) identify the most significant wavelengths linked to the physicochemical attributes, and (5) apply the prediction models to the hypercubes to obtain distribution maps depicting the variation of each attribute within the sample.

2. Materials and methods

2.1. Sample preparation

Fresh pork samples from the loin muscle (*longissimus dorsi*) at 24 h post-mortem were selected from different quality categories by trained inspectors to include a wide range of variation for quality attributes. All samples were prepared in a pilot scale abattoir (Meat Industry Development Unit, Teagasc – Ashtown Food Research Centre, Dublin) and cut into chops with a thickness of 2.5 cm before being vacuum packed and sent to the Computerized Food Technology Laboratory at University College Dublin, Dublin, Ireland for analysis and image acquisition. After scanning each sample, drip loss, color and pH were measured as described below (Section 2.2). For sensory analysis, pork chops were imaged, vacuum-packed, frozen and stored at −20 °C until the time of sensory evaluation, according to standard procedure [24]. The key steps for the whole procedure are presented in Fig. 1.

2.2. Measurement of quality attributes

A set of 75 samples was used for instrumental quality attributes measurements. Color (L, a and b values) and pH were measured for each sample after blooming for 30 min. The value of L is the color lightness and is often used to distinguish normal from pale or dark pork. Parameters a and b are termed opponent color axes; while a represents red (positive) versus green (negative) colors, b is positive for yellow colors and negative for blue colors. In addition, chroma ($(a^2+b^2)^{1/2}$) and hue angle (arctan b/a) were also calculated, as it has been shown that these parameters can change due to differences in quality [1,25,26]. Color features were obtained as the average of six measurements performed on the loin eye region of each sample using a Minolta Chromameter (CR-400, Konica Minolta Corp., Japan) calibrated against white ceramic tile. Ultimate pH was calculated as the average of four measurements acquired for the loin eye region using a portable pH-meter (AB15, Fisher scientific Inc., USA). Drip loss was determined using the bag method as a percentage of weight loss after 48 h storage at 4 °C [7].

2.3. Sensory evaluation

The loin samples were removed from the freezer approximately 24 h before sensory testing. Sensory evaluation was performed on 30 thawed samples in four separate sessions conducted during 2 days in individual booths under red lighting. Eight trained panelists from Ashtown Food Research Centre (AFRC, Dublin, Ireland) tasted samples of distinct pork classes. Each panelist tasted eight samples per session in two sets of four samples. The steaks for sensory analysis were grilled (Silesia Velox UK Ltd, Oxfordshire, UK) for 5 min to a 72 °C core temperature. Eight 15 mm × 15 mm squares were cut from the cooked steak, labeled with a three digit code and served to eight experienced in-house panelists. The panel rated tenderness and juiciness on a scale from one to eight. A scale of one to six was used for flavor and overall acceptability [24]. Panelists were instructed to cleanse the palate between samples with a bite of an unsalted cracker and a sip of water.

2.4. Collection and processing of hyperspectral images

2.4.1. Hyperspectral imaging system

The pushbroom hyperspectral imaging system shown in Fig. 2 consisted of a line-scan spectrograph (ImSpector, N17E, Spectral Imaging Ltd., Finland), a charged couple device (CCD) camera with C-mount lens (Xeva 992, Xenics Infrared Solutions, Belgium), two tungsten–halogen lamps corresponding to the illumination unit (V-light, Lowel Light Inc., USA), a translation stage (MSA15R-N, AMT-Linearways, SuperSlides & Bushes Corp., India), a data acquisition software (SpectralCube, Spectral Imaging Ltd., Finland) and a computer. The spectrograph had a fixed-size internal slit (30 μm) to define a field of view (FOV) for the spatial line (horizontal pixel direction) and collected spectral images in the reflectance mode, in the wavelength range of 897–1752 nm with a spectral increment