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Tenderness classification of fresh broiler breast fillets using visible and near-infrared hyperspectral imaging

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ABSTRACT

The aim of this study was to classify and visualize tenderness of intact fresh broiler breast fillets using hyperspectral imaging (HSI) technique. A total of 75 chicken fillets were scanned by HSI system of 400–1000 nm in reflectance mode. Warner-Bratzler shear force (WBSF) value was used as reference tenderness indicator and fillets were grouped into least, moderately and very tender categories accordingly. To extract additional image textural features, principal component analysis (PCA) transform of images were conducted and gray level co-occurrence matrix (GLCM) analysis was implemented in region of interests (ROIs) on first three PC score images. Partial least square discriminant analysis (PLS-DA) or radial basis function-support vector machine (RBF-SVM) was developed for predicting tenderness based on full wavelengths (CCR = 0.92), selected wavelengths (CCR = 0.84), textural or combined data (CCR = 0.88). Classification maps were created by pixels prediction in images and breast fillet tenderness was readily discernible. Overall, HSI technique is a promising methodology for predicting tenderness of intact fresh broiler breast meat.

1. Introduction

The consumption of poultry meat is growing steadily worldwide (FAO, 2014) due to the lower cost, high nutritional value, rapid growth, and greater diversity of further-processed product (Barbut, 2016). As a result, more attention is being paid to quality attributes that consumers are concerned with before making a decision to buy or rebuy. Since boneless skinless breast meat is the most popular chicken product in North American and many European countries, its quality properties are of great importance when it comes to consumer acceptance.

Tenderness is an important quality attribute, defined by the ease of mastication. It has been widely employed as an indicator for the eating quality of meat from consumers' perceptive (Boleman et al., 1997). Numerous techniques have been used to assess meat tenderness in poultry and other meats, including the instrumental approaches, such as Allo-Kramer method and the Warner-Bratzler shear force (WBSF) method, and sensory analytical methods employing human senses to directly evaluate tenderness (Cheatham, 2005). Although these techniques provide reliable information on meat tenderness, the methods are time-consuming, invasive or expensive for training and employment of panelists. Moreover, all the above methods must be conducted on the basis of cooked meat. However, in the meat industry, it is of more interest to be able to predict meat tenderness of cooked products based on measurements of fresh intact meat. Therefore, an efficient, non-destructive, reproducible, and sensitive technique, which could be developed and applied for meat tenderness evaluation is highly desirable.

Nowadays, the spectral methodologies of visible and near-infrared (Vis/NIR) or near-infrared (NIR) spectroscopy have been widely investigated for the quality prediction of meat (Prieto, Roehe, Lavín, Batten, & Andrés, 2009), such as beef (De Marchi, 2013; Prieto, Andrés, Giráldez, Mantecón, & Lavín, 2008; Zhang et al., 2015), pork (Balage et al., 2015a, b; Kapper, Klont, Verdonk, & Urlings, 2012; Savenije, Geesink, Van der Palen, & Hemke, 2006) and lamb (Andrés et al., 2007). Equally in the poultry industry, the capacity of Vis/NIR spectroscopy for estimating chicken meat quality attributes, such as pH (Berzaghi, Dalle Zotte, Jansson, & Andrighetto, 2005), color (Liu, Lyon, Windham, Lyon, & Savage, 2004), and water-holding capacity (Bowker, Hawkins, & Zhuang, 2014) has also been demonstrated. In particular, a prior study examining the tenderness of chicken meat using NIR spectroscopy generated positive findings (Cheatham, 2005). Spectroscopy is a sensitive, rapid, non-destructive, and reliable analytical technique with distinct advantages with regards to the simplicity of sample preparation, which are of practical importance in online assessment of meat quality (Prieto et al., 2009). However, as it is well known, the traditional spectroscopic method is limited by using average spectra on pre-selected areas, which may not be fully representative of the entire

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sample and also cannot be used to predict variations in texture quality in an intact piece of meat.

As a logical extension of combining spectroscopy with imaging techniques, hyperspectral imaging (HSI) has emerged as a novel analytical technology which could provide both spectral and spatial information of tested food samples (Sun, 2010). In the last decade, studies have been reported on evaluation of HSI for assessing quality and safety of a variety of food, such as agro-food (ElMasry, Kamruzzaman, Sun, & Allen, 2012), fruit and vegetables (Lorente et al., 2012), maize kernel (Wang et al., 2015), muscle food (Cheng, Nicolai, & Sun, 2017) and eggs (Liu & Ngadi, 2013). In the poultry industry, the HSI technique has also been applied to assess the physical and chemical attributes of chicken meat, such as, springiness (Xiong et al., 2015), freshness (Xiong et al., 2015), bacterial load (Feng et al., 2013; Feng & Sun, 2013), surface contamination (Yoon, Park, Lawrence, Windham, & Heitschmidt, 2011) and hydroxyproline content (Xiong, Sun, Pu, Zhu, & Luo, 2015), and classify free-range and broiler chicken meats (Xiong, Sun, Xie, Han, & Wang, 2015). Recently, a new approach of combining spectra and image textural data in HSI analysis has appeared, and the results are promising (Khulal, Zhao, Hu, & Chen, 2017; Liu, Pu, Sun, Wang, & Zeng, 2014; Xiong, Sun, Xie, Han, & Wang, 2015).

However, to the best of our knowledge, few studies have been conducted to evaluate the tenderness of chicken meat employing HSI. Since previous works on red meat tenderness prediction by this approach have revealed definite potential (Cluff, Naganathan, Subbiah, Samal, & Calkins, 2013; Kamruzzaman, ElMasry, Sun, & Allen, 2013; Naganathan et al., 2008), it is of interest to evaluate the technique for predicting white meat tenderness. Therefore, a study to evaluate the feasibility of the Vis/NIR HSI technique to classify intact fresh boneless and skinless broiler breast fillets (pectoralis major) and visualize the tenderness is warranted. Considering that tenderness is a texture property, it is really interesting to include image textural data in the spectral model for tenderness prediction.

The specific objectives of the present study were to: (1) extract spectral and image textural data from the regions of interest (ROIs), which were located in the same positions where WBSF measurements were performed in chicken fillets, in Vis/NIR (400–1000 nm) hyperspectral images; (2) compare partial least square discriminant analysis (PLS-DA) and radial basis function-support vector machine (RBF-SVM) modeling methods in full-wavelength models development based on different spectra preprocessing approaches for chicken breast fillets tenderness classification; (3) select the tenderness-related wavelengths by uninformative variable elimination (UVE) and successive projections algorithm (SPA), and evaluate the models performance based on the selected wavelengths, image textural features and combined data; and (4) conduct classification maps based on pixels prediction in hyperspectral images using the optimal model and visualize tenderness within broiler breast fillet and as an intact fillet.

2. Materials and methods

The main steps employed for assessing the tenderness of intact fresh broiler breast meat using Vis/NIR HSI are detailed presented in the flowchart in Fig. 1.

2.1. Sample preparation

On each of five replicate sampling days, immersion-chilled broiler carcasses, which were approximately six weeks old and processed following broiler processing practices for the US food service market, were collected for a local commercial plant. Carcasses were placed in plastic bags, covered with ice and transported in 36-L coolers (Igloo, Shelton, CT; internal dimension 52 × 30 × 35 cm) to the laboratory within 20 min (Zhuang & Savage, 2012). Breast fillets (alternating right and left) were deboned at 2 h, 4 h, or 24 h postmortem to yield a population of fillets with diverse tenderness. Visible fat and connective tissue were trimmed from fillets and a total of 75 boneless skinless broiler breast fillets (pectoralis major) were collected (15 fillets for each sampling day).

2.2. HSI system and image calibration

The imaging system used in this study was a pushbroom line-scan HSI system, which converts the Vis/NIR spectral range to capture hyperspectral images of chicken fillets in the reflectance mode. This system was composed of a spectrograph (ImSpector V10E, Specim, Oulu, Finland), a 12-bit CCD sensor (SensiCam QE SVGA, Cooke Corp., Auburn Hills, Mich.), a translation stage (STGA-10, Newmark Systems, Mission Viejo, Cal.) driven by a motion controller (NCS-1S, Newmark Systems, Mission Viejo, Cal.), a computer to control the camera and acquire images, and halogen lamps (Yoon et al., 2009). Each fillet was put on the translation stage after its surface liquid was removed with paper towel prior to the image capture. When the fillets entered the field of view, image acquisition would proceed by sequential (line by line) scanning. All the hyperspectral images acquired by the system contained 520 wavebands (between 368 and 1024 nm) with an image of 688 × 500 pixel resolution for each waveband. High noise images of the two spectral regions (368–400 nm, 1000–1024 nm) were excluded and the images in the spectral range of 400–1000 nm (473 wavebands) were retained for analysis.

To remove the dark current effect of the camera and to eliminate the effect of uneven illumination, image calibration was performed for the raw images. A white reference image was acquired from a white reference panel (~99.9% reflectance) and a dark reference image was obtained by covering the camera with its own opaque cap (~0% reflectance). A relative reflectance image was calculated using the following equation:

$$R_c = \frac{\mathrm{R_m} - \mathrm{D}}{\mathrm{W} - \mathrm{D}} \times 100\% \tag{1}$$

where R_c is the resulting calibrated image and R_m is raw acquired images. D is the dark current image and W is the white reference image.

2.3. Measurement of WBSF values

Fillets were cooked in a Henny Penny MCS-6 combination oven (Henny Penny Corporation, Eaton, OH) at 85 °C with the tender steam setting to reach an internal temperature of 78 °C. Temperatures of each fillet were checked in the thickest part using a hand-held digital thermometer equipped with a hypodermic needle probe (Doric Digital Thermometer, Model 450-ET, Doric Scientific, San Diego, CA) (Zhuang & Savage, 2009). After cooked fillets reached the desired temperature, two 1.9-cm-wide and 1.9-cm-thick strips were removed from the breast by cutting next to a template aligned parallel to the muscle fibers and adjacent to the cranial end. Each strip was sheared perpendicular to the longitudinal orientation of the muscle fibers through the middle part using a TA-XT *Plus* Texture Analyzer (Stable Micro Systems, Surrey, UK) combined with a TA-7 WB shear type blade. The blade was fitted with a 50 kg load cell and the maximum force was expressed as kilogram force (kg f) then converted to Newton (N) using Texture Exponent 32 software (Stable Microsystems, v.3.0.3.0, Surrey, UK) as the WBSF value (Zhuang, Savage, Smith, & Berrang, 2008).

2.4. Extraction of ROIs and spectral data

The selection of the ROI from a sample image is critical in image processing as it greatly influences the performance of models. To acquire more accurate and more relevant information to WBSF values, two rectangles corresponding to the accurate positions of the WBSF instrumental measurements (where there is also basically no specular reflection) were taken as the ROIs with sizes of 3600 (120 × 30) pixels for each (as shown in Fig. 1). The spectral data of all pixels in the ROI