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Rapid and non-destructive detection of chicken adulteration in minced beef using visible near-infrared hyperspectral imaging and machine learning

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ABSTRACT

The main objective of this study was to evaluate the potential of visible near-infrared (VNIR) hyperspectral imaging (400–1000 nm) and machine learning to detect adulteration in fresh minced beef with chicken. Minced beef samples were adulterated with minced chicken in the range 0–50% (w/w) at approximately 2% intervals. Hyperspectral images were acquired in the reflectance (R) mode and then transformed into absorbance (A) and Kubelka–Munck (KM) units. Partial least squares regression (PLSR) models were developed to relate the three spectral profiles with the adulteration levels of the tested samples. These models were then validated using different independent data sets, and obtained the coefficient of determination (R^2_p) of 0.97, 0.97, and 0.96 with root mean square error in prediction (RMSEP) of 2.62, 2.45, and 3.18% (w/w) for R, A and KM spectra, respectively. To reduce the high dimensionality of the hyperspectral data, some important wavelengths were selected using stepwise regression. PLSR models were again created using these important wavelengths and the best model was then transferred in each pixel in the image to obtain prediction map. The results clearly ascertain that hyperspectral imaging coupled with machine learning can be used to detect, quantify and visualize the amount of chicken adulterant added to the minced beef.

1. Introduction

Meat is a commonly consumed human diet throughout the world. In the last few decades, consumer demands have changed in terms of quality and safety traits (Andrée et al., 2010). Consumers are now more concerned about the meat and thus pay more attention in terms of high quality, safety, authenticity and animal welfare and also care for the environment and sustainability (Papadopoulou et al., 2011). Meat and meat products can be attractive targets for adulteration in many ways (Cozzolino and Murray, 2004; Ballin and Lametsch, 2008). Currently adulteration is a common problem throughout the world (Zhao et al., 2014). Practically it is very difficult to identify one type of minced meat from another as minced meat production removes the morphological structures of meat. That is why meat substitution by any cheaper lower-grade (inferior) material is one of the fraudulent acts in the minced meat industry that could result in economic and health problems (Meza-Márquez et al., 2010), causing concerns among consumers, producers, retailers and food regulatory bodies. Although the determination of meat authenticity and the detection of adulteration have received ample attention in the meat industry, the prevalence of meat fraud is not easy to assess. Therefore, it is necessary to have reliable analytical methods to confirm meat authenticity and detection of meat adulteration. A variety of standard analytical methods are available for detecting adulteration in minced meat. However, these traditional analytical methods are generally time-consuming, tedious, laborious, destructive and required skilled personnel or toxic pollution. Because of these disadvantages, these methods are normally not suitable for on-line detection and for large scale operations. Therefore, rapid, non-destructive and reliable techniques are required.

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Hyperspectral imaging is a novel technique that integrates both spectroscopic and imaging technique in one system for providing both spectral and spatial information for an object which otherwise cannot be achieved with either conventional imaging or spectroscopic techniques. Hyperspectral imaging is a technique whereby hundreds of single band images at a certain wavelength are captured, forming a three-dimensional structure of multivariate image data (hypercube) consisting of a spectrum for each pixel in the image. The technique has recently been accepted as one of the most powerful non-destructive imaging methods for predicting quality and safety attributes in different meat species as well as for building chemical images to show the distribution maps of these constituents in a direct and easy way. A number of studies have highlighted the aptitude of hyperspectral imaging coupled with multivariate analysis in meat. These applications include the prediction of different quality attributes and safety parameters in beef (ElMasry et al., 2012a, 2012b; Naganathan et al., 2008; Kobayashi et al., 2010; Peng et al., 2011; Wu et al., 2012), pork (Barbin et al., 2012; Qiao et al., 2007; Tao and Peng, 2014), lamb (Kamruzzaman et al., 2011; Kamruzzaman et al., 2012a, 2013a, 2012b, 2012c; Pu et al., 2014, 2015a), chicken (Feng and Sun, 2013; Grau et al., 2011; Kong et al., 2004; Nakariyakul and Casasent, 2008; Park et al., 2007, 2011), turkey (ElMasry et al., 2011; Iqbal et al., 2013) and fish (He et al., 2014; Wu et al., 2014).

However, the technology is not yet perfectly developed, with major bottlenecks such as high costs and difficulties in high speed data acquisition and processing have limited the use of this technology in a real time assessment. Nevertheless, hyperspectral imaging technology can be a very useful tool for selecting some important wavelengths for building a multispectral imaging system to meet the speed requirement of industrial production lines (Burger and Gowen, 2011). These important wavelengths may be equal or more efficient than full wavelengths if the wavelengths carrying most of the spectral information are selected (Wold et al., 1996). Indeed, the success of multispectral imaging heavily depends on the effectiveness of hyperspectral imaging for providing the feature wavelengths (Feng and Sun, 2012). In essence, if the high dimensionality of hyperspectral imaging data reduced properly by choosing some optimal wavelengths for specific applications, the technology would certainly be incomparable for process monitoring and real-time inspection (ElMasry and Sun, 2010; Kamruzzaman et al., 2015a; Pu et al., 2015b).

Nowadays, the visible near-infrared region (400–1000 nm) measured by charge-coupled device (CCD) array detectors, or the NIR region (900–1700 nm) measured with InGaAs detectors are frequently used as precursor to select some optimum wavelengths for the design of multispectral imaging systems. The 400–1000 nm range is advantageous because of the wide availability and low cost of CCD detectors compared with InGaAs detectors (Taghizadeh et al., 2009). To the best of our knowledge, only one study has investigated the detection of pork quantification in minced lamb using hyperspectral imaging in the spectral range of 900–1700 nm (Kamruzzaman et al., 2013b). No research has yet been conducted for detecting adulteration in minced beef using hyperspectral imaging. Therefore, it was our curiosity to develop a hyperspectral imaging system in the spectral range of 400–1000 nm as an analytical tool to detect adulteration in minced beef by chicken. The specific objectives of the current study were: (1) to develop a hyperspectral imaging coupled with PLSR to predict chicken adulteration in minced beef; (2) to compare three spectral profiles, i.e., R, A, and KM to find out the best spectra, (3) to select optimum wavelengths to design a multispectral imaging system for predicting adulteration in minced beef; (4) to develop image processing algorithms to generate pixel wise prediction maps for spatial detection of adulteration levels among and within the tested samples.

2. Materials and methods

2.1. Sample collection and preparation of adulterated samples

Pure minced beef and minced chicken were collected from a local supermarket. The minced beef samples were adulterated by mixing minced chicken in the range of 0%–50% (w/w) at approximately 2% increments. The minced beef and chicken were individually weighed and thoroughly mixed to obtain a homogenous sample with a total weight of 32 g. Samples were prepared in two different batches. In total 52 samples (2 samples per adulterate level × 26 levels) were prepared for the calibration set. On the other side, twenty six samples (1 sample per adulteration level) were prepared in different batch and used as a validation sample. As a result, a total of 78 samples consisting of 52 calibration samples and 26 validation samples were investigated for the study. Three pure chicken samples were also prepared for the study to show the spectral differences between pure beef and pure chicken. The minced meat was placed in a circular metal can (1.2 cm deep) and imaged using the hyperspectral system described below. The main steps for the whole procedure starting from sample preparation and image acquisition to multivariate analysis and ending with the prediction map are shown in Fig. 1.

2.2. Hyperspectral imaging system and image acquisition

Adulterated beef samples were scanned by using the laboratory-based VNIR hyperspectral imaging system in the spectral range of 400–1000 nm with 5 nm intervals producing a total of 121 bands. More details about the system can be found elsewhere (Siripatrawan et al., 2011; Kamruzzaman et al., 2015c). The system consists of a 12-bit charged couple device (CCD) camera with C-mount lens, a spectrograph, a conveying stage operated by a stepper motor and a computer supported with data acquisition software (SpectrumAnalyzer, version 1.8.5, JFE, Techno-Research Corporation, Tokyo, Japan). In order to illuminate the target sample and the field of view of the camera a light source consisting of a 150-W tungsten halogen lamp and a 150-W Xe lamp was fixed at an

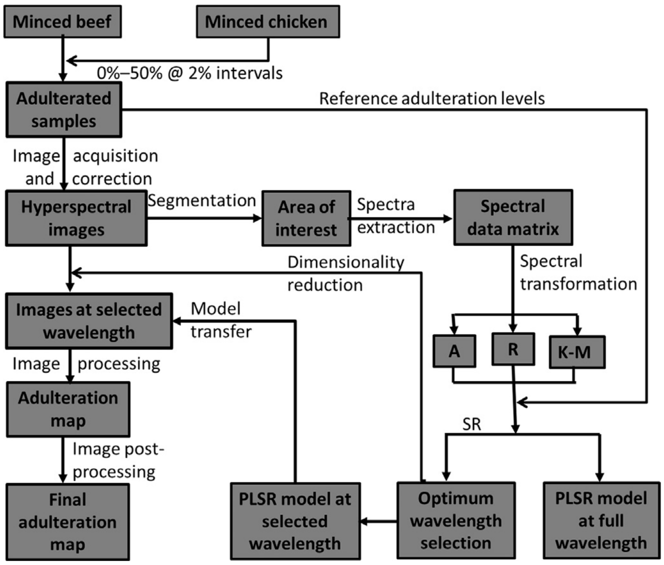

Fig. 1. Main steps for the whole process of hyperspectral image analysis.