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Rapid and non-destructive identification of water-injected beef samples using multispectral imaging analysis

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ABSTRACT

Water-injected beef has aroused public concern as a major food-safety issue in meat products. In the study, the potential of multispectral imaging analysis in the visible and near-infrared (405–970 nm) regions was evaluated for identifying water-injected beef. A multispectral vision system was used to acquire images of beef injected with up to 21% content of water, and partial least squares regression (PLSR) algorithm was employed to establish prediction model, leading to quantitative estimations of actual water increase with a correlation coefficient (r) of 0.923. Subsequently, an optimized model was achieved by integrating spectral data with feature information extracted from ordinary RGB data, yielding better predictions (r = 0.946). Moreover, the prediction equation was transferred to each pixel within the images for visualizing the distribution of actual water increase. These results demonstrate the capability of multispectral imaging technology as a rapid and non-destructive tool for the identification of water-injected beef.

1. Introduction

Beef is one of the most consumed meats in the world, with over sixty percent being consumed by only a handful of developed countries (Li, Shan, Peng, & Gao, 2011). Good-quality beef is an excellent source of protein and minerals, and therefore is highly desired. Recently, there has been a growing public awareness of food safety issues related to meat products, such as the illegal production of water-injected meat, fake beef and lamb, rotten meat, and toxic meat products. Due to the temptation of easy profits as well as technical difficulties in nondestructively identifying water-injected meat, the challenges of these scandals remain serious. In order to ensure the quality and safety of meat products, it is necessary to develop a rapid and effective quality evaluation method for identifying tainted meat.

In recent years, scientists have developed many techniques for nondestructive evaluation of meat quality, based on computer vision, infrared spectroscopy, hyperspectral imaging, magnetic resonance imaging etc. By combining nondestructive techniques with chemometrics analysis, several calibration models have been established and applied to various analytical determinations, including the evaluation of meat quality (Shiranita, Miyajima, & Takiyama, 1998), classification of bovine muscles (Basset, Dupont, Hernandez, Odet, & Culioli, 1999), prediction of moisture, protein, fat and caloric content of raw pork and beef (Lanza, 1983), classification of beef tenderness (Cluff et al., 2008; Naganathan et al., 2008), classification of frozen-thawed meats (Lagerstedt, Enfält, Johansson, & Lundström, 2008; Song & Liu, 2014), prediction of heme and non-heme iron contents in pork sausages (Ma et al., 2016), and detection of microbial spoilage of beef (Ma et al., 2014; Peng et al., 2011). However, there is no report to date regarding the application of non-destructive methods for identifying water-injected beef.

As is well known, water is the main component of meat and water content is the key index of meat quality in the meat processing industry (Mathlouthi, 2001). Nowadays, illegally water-injected meat has become one of the major issues regarding the quality controlling and biosafety of fresh meat (Yang et al., 2013). Injection of water into meat samples is an illegal process as it involves violation of the relevant food sanitation and slaughter laws, and the use of artificial tools, such as injectors, and pressure pumps, to inject an amount of water, before or after the livestock

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and poultry is slaughtered, in order to increase the weight of the meat. Water injection can cause a dramatic expansion of cellular volumes, rupture of cells and protein loss, leading to a degradation of meat quality. Moreover, the injected water usually contain microorganisms, pathogens, toxins and other harmful substances, which would accelerate the spoiling of meat and shorten the freshness lifetime (Liu, Ai, Lu, & Liu, 2012). Till now, water-injected contamination has been reported in a wide range of meat, including beef, lamb, pork, poultry meat and other meat products. The permitted level of moisture in meat of livestock and poultry is specified by a couple of international and national standards. For example, Chinese standard GB 18394-2001 stipulates that the moisture content of pork, beef and chicken should not be more than 77%; while the moisture content of lamb is required to be less than 78%. At present, the two most widely used methods for meat moisture measurement are infrared moisture analyzer (Sleagun & Popa, 2009) and classic weight measurement method using oven-drying or microwave drying (Benedito, Carcel, Rossello, & Mulet, 2001). Infrared moisture analyzer can obtain stable recordings on sample with good uniformity, but its ability to cope with raw meat with inhomogenous texture is relatively weak. Classic weight measurement method is quite precise, yet it is time-consuming and invasive. The disadvantages of these two methods make them unsuitable for monitoring the moisture content in meat product continuously and non-destructively. Meanwhile, traditional methods such as touching, smelling, visual inspection etc., cannot accurately identify water-injected meat (Liu et al., 2012). Therefore, it is in urgent need of developing a rapid and effective method for identifying water-injected meat.

Hyperspectral/multispectral imaging is an emerging nondestructive technology that integrates conventional imaging and spectroscopy to attain both spatial and spectral information from an object simultaneously. Previous studies showed that the moisture content of meat during different dehydration stages could be determined by hyperspectral imaging (Wu et al., 2013). Also, visible-near-infrared spectroscopy has been examined as a tool for rapid determination of the water-holding capacity (WHC) of meat (Prevolnik, Čandek-Potokar, & Škorjanc, 2010; Samuel, Park, Sohn, & Wicker, 2011). Chemical-free determination and mapping of the major constituents (water, fat and protein) of meat has been performed using near-infrared spectroscopy (Ripoll, Albertí, Panea, Olleta, & Sañudo, 2008; Tøgersen, Isaksson, Nilsen, Bakker, & Hildrum, 1999). However, the rich information in hyperspectral imaging results in difficulties in data processing, which makes it hard for industrial online applications. Recently, a simplified multispectral imaging (MSI) has been increasingly applied as a powerful analytical tool for nondestructive quality determination for the agri-food (Liu, Liu, Lu, Ma, et al., 2014).

Recent studies showed that multispectral imaging is especially suitable for rapid and non-invasive identification of a range of quality-related components, provided that these components have spatially variable spectral responses (Liu, Liu, Chen, Yang, & Zheng, 2015; Liu, Liu, Lu, Chen, et al., 2014; Ma et al., 2014; Xiong et al., 2015). By combining with chemometrics, multispectral imaging use both spectral and spatial information to establish prediction models, resulting in much more stable prediction performances than NIR spectroscopy. Multispectral imaging technology has also been reported to perform better than colorimeter for the assessment of meat color, as multispectral vision system with diffuse illumination could provide a color-richer assessment of fresh meat samples with a glossier surface (Trinderup, Dahl, Jensen, Carstensen, & Conradsen, 2015). Due to the advantages of the multispectral imaging technology, the objective of this study was to investigate the feasibility of using this technique for the identification of water-injected meat and visualization of the water distribution pattern in meat samples.

2. Materials and methods

2.1. Beef samples

Beef was purchased from Carrefour supermarket, Hefei, China as a single stock sample. The fresh and vacuum-packaged beef was placed into an ice-box and transported to the laboratory. The beef was sectioned into four pieces, and then frozen and stored at −20 °C until it was used (within 4 days). Immediately prior to analysis, the frozen beef was removed from the refrigerator and cut into uniformly sized samples (length × width × height = 3 cm × 2 cm × 1 cm). After the beef samples had been thawed for 12 h in the refrigerator (4 °C), water was injected into the exact center of the sample with a syringe (0.5 mL). After the water injection, the unabsorbed water of the beef samples were sucked by filter paper and the samples allowed to stand for 10 min at room temperature prior to performing subsequent analyses.

The beef samples were divided into two sets, calibration and prediction sets. The calibration set had 15 beef samples and the percentage of injected water in each sample was in this order: 0%, 3%, 6%, 9%, 12%, 15%, 18% and 21%. The prediction set had 12 beef samples and the percentage of injected water in each sample was: 4%, 6%, 8%, 10% and 12%.

2.2. Measurement of moisture content of beef samples

The experimental determination of the moisture content of beef samples was performed in two sections. In the first section, the percentage increase of the water content in the beef samples was determined based on the classic weight measurement method. For this method, the beef samples were weighed using an analytical balance (accuracy, 0.0001 g) before and after injection of water to measure the weight changes. In the second section, the drying method was used to measure moisture content of the 27 beef samples (calibration set had 15 samples, prediction set had 12 samples), according to the procedure specified by GB/T 5009.3-2010. All beef samples were weighed (the weight of each sample was between 6–9 g) before performing the injection test. After completing all the experiments, the beef samples were placed into glass weighing bottles, which were then placed in an Electrothermal Constant-temperature Drying Box at 105 °C for 4 h. The bottles were then removed and immediately cooled in glass vacuum desiccators (containing allochroic silica gel) for 30 min. The beef samples were then weighed again to get a constant weight.

2.3. Multispectral imaging system

The multispectral images of beef samples (placed in a petri dish of 90 mm diameter and 11 mm depth) were captured using a VideometerLab equipment (Videometer A/S, Hørsholm, Denmark), which acquired multispectral images at 19 different wavelengths ranging from the visible (VIS) region to the NIR region. The actual wavelengths used in the study were 405, 435, 450, 470, 505, 525, 570, 590, 630, 645, 660, 700, 780, 850, 870, 890, 910, 940, 970 nm, and it can be seen that the majority of the wavelengths are in the visible region of the spectrum (400–800 nm). Fig. 1 shows the instrumental setup of the multispectral imaging system. The VideometerLab is a high performance spectral imaging system which has a wide range of applications including imaging of chemical composition, colors or surface structures. The unit is an easy-to-use system which integrates illumination, camera, and computer technology with advanced digital image analysis and statistics. The technology is particularly useful for