Talanta 139 (2015) 208–215

Contents lists available at ScienceDirect

Talanta

journal homepage: www.elsevier.com/locate/talanta

Rapid detection of frozen pork quality without thawing by Vis–NIR hyperspectral imaging technique

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ARTICLE INFO

Article history:
Received 29 October 2014
Received in revised form
6 February 2015
Accepted 17 February 2015
Available online 25 February 2015

Keywords:
Hyperspectral imaging
Frozen food
Freezing
NIR spectroscopy
Drip loss
Meat color

ABSTRACT

Quality determination of frozen food is a time-consuming and laborious work as it normally takes a long time to thaw the frozen samples before measurements can be carried out. In this research, a rapid and non-destructive determination technique for frozen pork quality was tested with a hyperspectral imaging (HSI) system. In this study, 120 pieces of pork meat were frozen by four kinds of methods with various freezing temperatures from −20 to −120 °C. The hyperspectral images of the samples were acquired at the frozen state. Quality indicators including drip loss, pH value, color, cooking loss and Warner–Bratzler shear force (WBSF) of the samples were measured after thawing. The spectral characteristics of the frozen meat samples were studied and it was revealed that the reflectance at 1100 nm had a close relationship with the freezing temperature ($R=-0.832$, $p<0.01$). Partial least squares regression (PLSR) was applied to establish the spectral models, and the models were then optimized. Results showed that the improved region of interest (ROI) method could be used to extract effective spectral information to withstand the interference of freezing, and choosing appropriate spectral bands and spectral pretreatment techniques were crucial to develop robust mathematical model. The performances of the models established were diverse based on different quality indicators. The coefficients of determination for prediction (R_p^2) for L^*, cooking loss, b^*, drip loss and a^* were 0.907, 0.845, 0.814, 0.762, and 0.716, respectively. However there were low correlations (R_p^2) for pH and WBSF measurements. The current study indicated that HSI had the potential for non-destructive determination of frozen meat quality without thawing.

1. Introduction

Quality is considered as a key factor for the development of the agricultural and food industry, and the industry often requires methods and techniques such as drying [41–44], refrigeration [45–50] and edible coating [51] to ensure product quality. Pork is one of the most valuable meat products and is the primary choice for people to obtain protein. However pork meat is perishable [1], therefore refrigeration especially freezing is a common technique to maintain its quality. When meats are in frozen state, it is not easy to determine their quality. Therefore the frozen meat market is mixed with superior and inferior products. It was reported that some food companies froze expired or inferior meats and sold them [2]. In addition, different freezing techniques can also have influences on the quality of frozen meats [3,4]. For example, slow freezing can promote the growth of large ice crystals, which could damage cell structure, upon thawing, it can cause more loss of meat juices [5,6] and color fading or darkening. Furthermore, temperature fluctuations during refrigeration storage can also deteriorate the quality of the frozen foods, causing protein denaturation and fat oxidation [7], and spoilage [8,9]. Therefore, it is essential to ascertain the quality of frozen food products [52].

Many indicators could be used to characterize the quality of frozen pork meats including water holding capacity [53], drip loss after thawing, cooking loss, pH, color, and tenderness (Warner–Bratzler shear force). Among them, drip loss and cooking loss are two important indexes that have direct impact on the economic benefits of a company.

Traditional methods are used to measure these quality indicators. Drip loss and cooking loss are measured by weighing the thawed or cooked sample and then comparing the weight with the initial weight of the frozen samples. In measuring drip loss,

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http://dx.doi.org/10.1016/j.talanta.2015.02.027
0039-9140/

samples are usually thawed for 12 or 24 h [10]. The pH value can be determined by a pH meter, and its changes with storage time could indicate the freshness of the samples [11,12]. Pork color can be measured by a colorimeter, which impacts on sensory evaluation and consumer desires. Tenderness reflects the palatability of the products, and can be determined by Warner–Bratzler shear force. All these measuring techniques are time-consuming and, in particular, cannot meet the requirement of on-line measurements. Although some rapid detection studies have been carried out, for example Hardy et al. [13] detected the microbial contamination in frozen vegetables by automated impedance measurements and Koch et al. [14] used rapid polymerase chain reaction method to detect *Vibrio cholerae* in foods, these studies focused on only microbiological detection, especially, it still needed a long time (more than 5 h) for testing. Therefore rapid and non-destructive detection technique for more quality indicators is needed.

Hyperspectral imaging (HSI) is a novel non-destructive evaluation method, which has been widely investigated for applications in the agricultural and food industry [15,16]. Based on the combination of spectroscopy and imaging or computer vision [54–59], HSI provides both spatial and spectral information for each pixel in the image. Therefore HSI can not only capture the external attributes (size, color, shape, surface texture, etc.) as traditional imaging technology, but can also be able to identify the chemical composition [17] in food as spectroscopic technique. Many studies have been conducted on using HSI for determining the quality of meats [60–66]. ElMasry et al. [18] developed a near-infrared (NIR) HSI (900–1700 nm) system for the measurement of surface color, pH and tenderness of fresh beef, Li et al. [19] used 400–1100 nm HSI to assess beef-marbling grade and obtained a good result with R^2=0.92. Similar techniques were also employed to detect microbial contamination of porcine meat [20,21], chicken contamination [22], lamb meat quality [23] and so on. In particular, Barbin et al. [24] evaluated the fresh and frozen-thawed porcine *longissimus dorsi* muscles by NIR HSI. Similar study was also reported by Cheng et al. [25] for fish fillets. However in these studies, the frozen samples were thawed and then their images were acquired at room temperature by HSI. To the best of our knowledge, no research is available on using HSI technique to acquire food images at frozen state without thawing, and directly evaluate the frozen food quality.

Therefore, the current study paper aimed to study a rapid and non-destructive technique based on hyperspectral imaging for direct measurement of frozen pork meat quality. The study also aimed to extract the spectral features of the frozen samples and to evaluate the impact of ice and frost on spectral detection.

2. Materials and methods

The main steps of this experiment are shown in Fig. 1, which included freezing pork meat samples, image acquisition, measurement of quality indicators, spectral analysis, modeling and optimizing, and visualization. The experimental procedures are detailed below:

2.1. Freezing pork samples

Longissimus dorsi meat samples from 10 pigs were obtained from a local market at 0.5 day post-mortem. Then the pork samples were cut into 120 pieces (4 cm × 5 cm × 10 cm) with mass of 200 ± 4 g. These pork samples were frozen by four kinds of techniques including cryogenic freezing using liquid nitrogen, immersion freezing, air-blast freezing and domestic freezing in a conventional refrigerator. The main parameters of the freezing processes are presented in Table 1. T–type thermocouple was

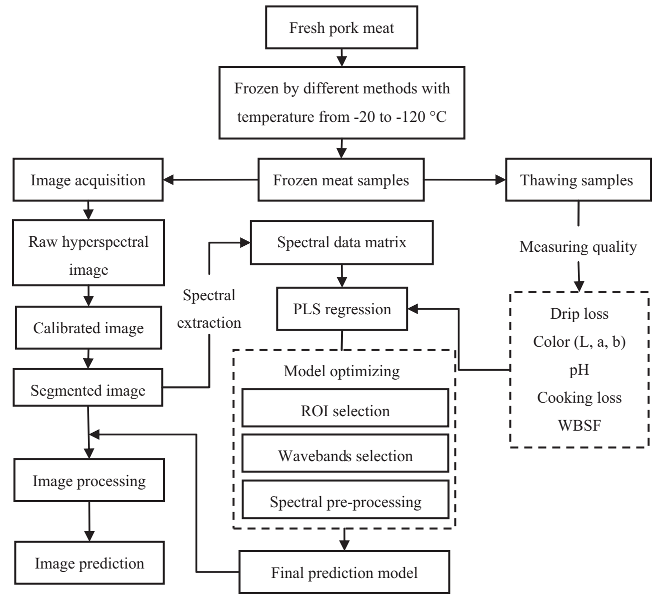

Fig. 1. Main steps of the experimental procedure.

inserted into the center of the sample to record the temperature variation with a data logger (TC-08, Pico Technology, Cambridgeshire, UK). There were a total of 120 samples, and each group of experiments contained 5 samples. When the core temperature of all 5 samples of one group reached −20 °C, the samples were moved into a refrigerator (BL/BD-719H, Haier Ltd., Qingdao, China) to store for 3 days at −20 °C.

2.2. Hyperspectral imaging system

Spectral images were acquired by a hyperspectral imaging system shown in Fig. 2, which included a visible (Vis) unit (400–1000 nm) and a NIR unit (900–2500 nm). The Vis hyperspectral imaging system consisted of a camera lens (OLE23, Schneider, Rueil, German), a spectrograph (Imspector V10E, Spectral Imaging Ltd., Oulu, Finland) for the spectral range of 400–1000 nm, a high performance 1004 × 1002 charge coupled device (CCD) camera (DL-604 M, Andor, Belfast, Ireland), two 150 W halogen lamps (2900-ER, Illumination Technologies Inc., New York, USA) forming the illumination unit. The NIR unit consisted of a C-mount lens, a 12-bit CCD camera (XEVA 992, XC 130 XenICs, Leuven, Belgium) with 320 × 300 pixels, a spectrograph (ImSpector N17E, Specim, Oulu, Finland) covering the spectral range of 900–2500 nm, and an illumination unit of two 500 W tungsten halogen lamps (Lowel V-light™, NY, USA). The common parts of this Vis–NIR hyperspectral imaging system were a translation stage operated by a steppermotor (IRCP0076-1COMB, Isuzu Optics Co., Taiwan, China), and a computer supported with a data acquisition software (Spectral Image software, Isuzu Optics Co., Taiwan, China).

2.3. Image acquisition and calibration

The difference of the Vis–NIR HSI system used in the current study from common hyperspectral imaging systems used in most studies was that a mini refrigerator (FYL-YS-30L, Fuyilian Co., Beijing, China) was installed on the translation stage. The temperature of the refrigerator was set at −20 °C. In the process of acquiring image, frozen pork sample was put in the refrigerator to avoid thawing. Every sample was scanned twice, i.e., the Vis image was acquired at the first, and then the NIR image was obtained by switching from the Vis system to the NIR system.

In order to reduce the noise of the images, the acquired images were calibrated to obtain the calibrated image (R) using the