BIOSYSTEMS ENGINEERING 162 (2017) 40–56

Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/issn/15375110

Research Paper

Determination of the moisture content of fresh meat using visible and near-infrared spatially resolved reflectance spectroscopy

Jian-Xu Wang [a,b], Li-Feng Fan [a,c], Hai-Hua Wang [a,b], Peng-Fei Zhao [a,c], Hao Li [a], Zhong-Yi Wang [a,b,c], Lan Huang [a,b,c,*]

[a] College of Information and Electrical Engineering, China Agricultural University, Beijing 100083, China

[b] Modern Precision Agriculture System Integration Research Key Laboratory of Ministry of Education, Beijing 100083, China

[c] Key Laboratory of Agricultural Information Acquisition Technology (Beijing), Ministry of Agriculture, Beijing 100083, China

ARTICLE INFO

Article history:
Received 4 August 2016
Received in revised form
23 May 2017
Accepted 21 July 2017

Keywords:
Spatially resolved reflectance spectroscopy
Intact pork
Moisture
Partial-least-squares regression
Successive-projection algorithm
Variable selection

The moisture content of intact pork meat was determined employing near-infrared non-destructive reflectance spectroscopy. The effects of various factors, namely the shape of the probe, the contact between the probe and sample and the modelling method, were also evaluated. Wavelengths in the range from 600 to 1100 nm, two spectra collection methods and three corresponding data processing methods were considered. Spectra were collected using a conventional Y-shaped optical fibre probe and an optical probe for steady-state spatially resolved detection. In the experiments, we can obtain the spectral information from the depth approximately 3 mm–4 mm or 4 mm–5 mm when the separation of the detector and the source is 6 mm or 9 mm, respectively. Models were established using data obtained with the steady-state spatially resolved probe (41 samples) and the Y-shaped optical probe (28 samples). Using the three-wavelength and Partial-least-squares regression (PLSR) calibration methods, the Y-shaped probe provided models with R^2 values of 0.0097 and 0.36 respectively, whereas the steady-state spatially resolved probe provided models with R^2 values of 0.3692 and 0.7769 respectively. Applying a successive-projection algorithm combined with multiple linear regressions to the data of the steady-state spatially resolved probe, the R^2 of the obtained model was 0.8078. Near-infrared steady-state spatially resolved spectroscopy is thus an effective technique for predicting the moisture content of intact pork.

* *Corresponding author*. College of Information and Electrical Engineering, China Agricultural University, Beijing 100083, China.
E-mail addresses: hlan@cau.edu.cn, biomed_hl@263.net (L. Huang).

http://dx.doi.org/10.1016/j.biosystemseng.2017.07.004

Nomenclature

WBSF	Warner–Bratzler shear force (N)
NIR	Near infrared reflection
FT-NIR	Fourier transform near infrared
NIRS	Near-infrared spectroscopy
PLSR	Partial-least-squares regression
SRS	Spatially resolved reflectance spectroscopy
TVB-N	Total volatile basic nitrogen (mg/100 g)
SPA	Successive-projection algorithm
MLR	Multiple linear regression
RMSEC	Root-mean-square error of calibration
PRESS	Predicted residual sum of squares
RSD	Relative standard deviation
R^2	Correlation coefficient
OD	Optical density (dimensionless)
DPF	Differential path length factor (dimensionless)
μ_s	Scattering coefficient (mm^{-1})
μ_s'	Reduced scattering coefficient (mm^{-1})
μ_a	Absorption coefficient (mm^{-1})
z_0	Detection depth (mm)
d	Distance between the source and the detector (mm)
I_s	The intensity of the diffuse reflectance spectrum (cd)
I_{100}	The intensity of the total reflection spectrum (cd)
I_b	The intensity of the background spectrum (cd)

1. Introduction

Determining the quality parameters of pork is essential for many processes in the food industry because consumers demand the highest quality of meat and meat products. Several studies have used near-infrared (NIR) spectroscopy to investigate the moisture, protein and fat contents of minced meat and other quality traits affecting the quality of meat, such as the water holding capacity, Warner–Bratzler shear force (WBSF), pH, colour and drip loss (Prevolnik, Candek-Potokar, & Skorjanc, 2004; Prieto, Roehe, Lavin, Batten, & Andres, 2009; Tao, Yang, Deng, & Zhang, 2013). Drip loss in meat has been predicted using near-infrared spectroscopy (NIRS) with a comparison of back propagation and counter propagation artificial neural networks and partial-least-squares regression (PLSR) modelling techniques, providing R^2 values of 0.38, 0.37 and 0.45 respectively (Prevolnik, Candek-Potokar, Novic, & Skorjanc, 2009). Prieto et al (2014) measured protein, moisture and fat contents in minced meat using NIRS and analysed the data using PLSR, obtaining R^2 values of 0.85, 0.90 and 0.86 respectively. Huang, Zhao, Zhang, and Chen (2012) analysed fat, sugar and protein contents during bacterial decomposition using Fourier transform near infrared (FT-NIR) spectroscopy and compared the results obtained from three data processing methods. The chemical composition of Thai steamed pork sausages has also been analysed by NIRS with regression models developed using PLSR (Ritthiruangdej, Ritthiron, Shinzawa, & Ozaki, 2011).

In recent years, NIRS analysis has been widely used to measure the moisture content of minced and intact pork (Alander, Bochko, Martinkauppi, Saranwong, & Mantere, 2013; Collell, Gou, Arnau, Munoz, & Comaposada, 2012; Huang, Yu, Xu, & Ying, 2008; Liao, Fan, & Cheng, 2010; Maja, Martin, Dejan, & Marjeta, 2010; Prieto, Ross et al., 2009; Zamora-Rojas, Garrido-Varo, De Pedro-Sanz, Guerrero-Ginel, & Pérez-Marín, 2011). The moisture content of minced meat has also been measured satisfactorily (Cheng, Fan, & Liao, 2012; Fan, Liao, & Cheng, 2011; Huang, Zhao, Chen, & Zhang, 2014; Prieto, Ross et al., 2009; Tao et al., 2013).

However, the few models previously developed for predicting the moisture content of intact meat using NIRS have been much less satisfactory than those for minced meat. One study predicted four quality attributes of intact pork, namely the pH, colour, WBSF and intramuscular fat, using NIRS with a Y-shaped cable fibre (Balage, da Luz, Gomide, Bonin Mde, & Figueira, 2015). PLSR was used to establish a validation model and the results for the four quality attributes provided R^2 values of 0.75, 0.77, 0.25 and 0.33 respectively. The R^2 of the WBSF is poor partly owing to the limited variation in tenderness. Another study detected quality attributes of beef, namely the pH, colour and WBSF, using NIRS and processed the data using PLSR (De Marchi, 2013). The freshness and tenderness of pork were assessed by detecting the total volatile basic nitrogen (TVB-N) and WBSF using the FT-NIR spectroscopy technique (Chen, Cai, Wan, & Zhao, 2011). PLSR was used to process the spectroscopic data with R^2 values of 0.6780 for TVB-N and 0.4786 for WBSF. Further research on applying NIRS is required for estimating the meat quality attributes of intact meat.

Recently, the quality of intact meat has been studied using hyperspectral imaging, which can provide useful spatially resolved spectroscopic data (Barbin, Elmasry, Sun, & Allen, 2012; Kamruzzaman, Makino, & Oshita, 2015; Qiao et al., 2007). However, hyperspectral imaging instruments are expensive and data processing is complex, and a low-cost analysis method is thus required to obtain the spatially resolved spectrum information using a convenient spectroscopy instrument with an appropriately designed probe. Indeed, the hyperspectral imaging instruments cost approximately RMB 400,000 to 800,000 each, compared with a price of RMB 18,000 for the common spectrometer when using our proposed method, which allows more flexible application. In our study, the probe can adapt to different spectral instruments and light equipment easily with a low cost. The probe has the characteristics of universality, easy operation and low cost.

Different studies provide different results with many factors leading to these differences, such as the functions and settings of the NIR equipment, the number and types of samples, the chemometric techniques used and the experimental conditions (Kapper, Klont, Verdonk, & Urlings, 2012; Kapper, Klont, Verdonk, Williams, & Urlings, 2012). Different measurement methods, samples and methods of data analysis using NIRS have been compared for applications in food analysis (Alander et al., 2013). Alander et al. reviewed four kinds of measurement modes for the acquisition of NIR spectra from a sample in food detection applications: transmission, reflection, transflection and interaction. In the