Engineering in Agriculture, Environment and Food 9 (2016) 195–199

Contents lists available at ScienceDirect

Engineering in Agriculture, Environment and Food

journal homepage: http://www.sciencedirect.com/eaef

Research paper

The study on the quality evaluation method for beef cut by using visible and near infrared spectroscopies

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ARTICLE INFO

Article history:
Received 11 April 2015
Received in revised form
11 September 2015
Accepted 18 December 2015
Available online 21 December 2015

Keywords:
Band shift
Beef
Moisture content
PLS regression
Visible and near infrared spectroscopy
Water activity

ABSTRACT

This paper presents a nondestructive method for evaluating changes in the moisture content and in the interaction between contents such as protein and water molecule in beef cut by using visible and near infrared spectroscopies. Spectral variations in the 450–1100 nm region were measured for a beef cut using two types of spectrometers. Bands were observed in the 540–570, 600–660 and 920–980 nm regions according to the change in moisture contents. The PLS regression of moisture contents by using the second derivative in the 920–980 nm region provided a very good predictive model with $R^2 = 0.96$ and RMSE = 0.04. Moreover a band in the 600–660 nm shifted to longer wavelength in the 0.9–1.0 of water activity range and then this band slightly shifted to shorter wavelength in the lower water activity range. This spectral behavior may reflect the appearance and oxidation of myoglobin due to dry in/on beef. Simultaneously, it is very likely that the behavior of each water state; free and bonded can describe well by that band shift. These results obtained therefore provide a fundamental chemical understanding of band behavior in the 600–660 nm region and suggested that one can evaluate the quality degradation in beef cut by using visible and NIR spectral region.

1. Introduction

Quality evaluation during food production is very important to ensure suitable management practices. In many cases, manual evaluations based on picked up tests can provide highly accurate estimates of food quality (Costa et al., 2001; Brosnan and Sun, 2004; Du and Sun, 2006). However, these tests require great time and labor, and general evaluations typically require manual work and rely on the expertise of the personnel involved.

In the case of meat, reliable information regarding several parameters related to quality, such as the moisture, protein, and fat contents, should be obtained throughout the production process (Liu et al., 2003). In particular, the development of fast, accurate, and non-invasive techniques is essential for the quality control of meat (Damez and Clerjon, 2008).

Several spectroscopic techniques have recently been employed to sufficiently meet the above needs. Because visible spectroscopy in the range of 400–750 nm provides direct information about myoglobin, which causes quality degradation in meat, a number of studies have focused on band behavior due to myoglobin absorption in the visible region (Millar et al., 1996; Liu et al., 2003).

Infrared (IR) bands in the 4000–100 cm^{-1} region are a strong indicator of meat quality because they directly reflect molecular vibrations from meat components such as water, protein and fat (Al-Jowder et al., 1999; Gangidi and Proctor, 2009; Rohman et al., 2011). However, for thick samples such as the meat, the strong absorption is frequently rather obstacle for the correct detection. On the other hand, near-infrared (NIR) spectra in the 800–2500 nm region correspond to molecular vibrations along with the IR region, and are more complicated than the IR spectra owing to the number of overtone overlaps and combination bands (Ozaki and Kawata, 1996). However various superior features of NIR spectroscopy such as high-speed monitoring, repeatability, and non-invasiveness enable quantitative and qualitative analyses of food. Therefore, the quantitative analysis of chemical components in meat has been determined using NIR spectra combined with partial least square regression (PLSR) (Mitsumoto et al., 1991; Liu et al., 2003; Prieto et al., 2009; Collell et al., 2011). This method can be used to detect functional vibrations and is very powerful for determining

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http://dx.doi.org/10.1016/j.eaef.2015.12.001
1881-8366/

the chemical characteristics of meat, such as the water and protein content. It is therefore very attractive that visible and NIR spectroscopies provide complementary insight not only into meat quality, but also chemical behavior including interactions between components.

Although the moisture content in raw meat is an integral part of the evaluation of quality, it is more important to note that water activity responded to water status in a sample provides one powerful evaluation result of the quality (Aktaş and Gürses, 2005). However, to the best of our knowledge, few studies have examined water status as it relates to water activity using spectroscopic technology (Collell et al., 2011). Additionally, in the previous study, spectral behavior such as the band shift has not been fully discussed with respect to the water status of meat, and their physical and chemical interpretations.

In the present study, beef was selected as a meat sample, and changes in moisture content were analyzed quantitatively by visible and NIR spectroscopy in the 450–1100 nm region combined with PLS regression. Moreover, spectral changes such as band shifts in visible spectra that are related to water status in beef were investigated. The results of this study reveal the potential for evaluating the degradation of beef cuts using spectroscopic technologies.

2. Materials and methods

2.1. Sample preparation

In this study, two sample sets were prepared to use as the calibration and validation data set of the quantitative analysis. The both sets included 50 and 18 samples of beef shoulder clod (beef cut) without fat, respectively. In production line, samples were trimmed to $2 \times 4 \times 4\ \mathrm{mm}^3$. In their initial state, the samples mainly consisted of approximately 22% protein, 4% lipids, 0.52% sodium, and water. Calibration data set was subjected to drying at 2 °C in a low-temperature chamber. To evaluate robustness of the predictive model, 18 samples of validation data set were prepared under the several drying condition. Four of them were dried at 2 °C refrigerator, and six of them were subjected to air drying at 35 °C in an incubator. The others (eight of them) were dried at 2 °C refrigerator for two days, and then they were moved to the 35 °C incubator to dry. The water gradient between each sample was controlled by drying time.

Each sample was homogenized by mixer (IMF-720G IWATANI co., Osaka, Japan), respectively. Approximately 2 g was weighted from each homogenized sample, and they were used to measure water activity and moisture contents. Water activity of each sample was measured by water activity analyzer (AquaLab 3 TE, AINEX Co. Ltd., Tokyo, Japan). And then the sample was dried at 135 C for 2 h and it is reweighed to obtain the dry weight, respectively. Finally, moisture contents at each time were calculated by the difference between the initial (approximately 2 g) and the dry weight.

2.2. Spectral data collection

The diffuse reflectance spectra in the 450–750 nm and 700–1100 nm regions were measured at approximately 1-nm intervals using a visible spectrometer (FieldSpec Handheld 2, ASD, Inc., Boulder, CO, USA) and a NIR spectrometer (FAT-Analyzer S-7040, Soma Optics Co., Tokyo, Japan). A spectrometer equipped with a silicon detector such as the visible spectrometer can measure a spectrum in the 400–1100 nm region. However, the accuracy of this detector is low for the 800–1100 nm region, and the expected band due to moisture absorption is quite week. Therefore, accurate detection requires parallel measurements by two spectrometers, and this method was implemented in the study.

An overview of the spectral measurements for each region is shown in Fig. 1. Each prepared sample was placed on a black plate coated with black ink to avoid the acquisition of indirect energy due to re-irradiance. The visible spectrometer unit was placed on a tripod and positioned in the direction of 40° from the nadir, and a path length of 30 cm (between the sample and the visible spectrometer unit) was maintained for all measurements (Fig. 1(a)). All spectral measurements using the NIR spectrometer were performed in a low-temperature chamber at 4 °C (Fig. 1(b)). The measurement device contacted the sample surface, and the incident light from a halogen lamp in the spectrometer reached each sample through an optical fiber. Ten scans for each spectral measurement were conducted to ensure an adequate single-to-noise ratio of the spectra obtained from the sample. Reference measurements were carried out prior to the sample measurements.

2.3. Quantitative analysis

The spectral data corresponding to the moisture contents of 50 samples of the calibration data set *i.e.*were employed for model calibration. Each model was evaluated based on the coefficient of determination (R^2) and the root mean-squared error (RMSE). The changes in moisture content may largely influence spectral behavior, so only one PLS factor was defined to avoid overfitting. Finally, 18 samples of validation data set were used to evaluate the prediction potential of the optimal model.

3. Results and discussion

3.1. Adsorption isotherms

The adsorption isotherm for each sample is shown in Fig. 2. A slight increase in moisture content was observed in the 0.85–0.96 range of water activity. For a water activity (aw) of 0.96–1.00, the slope indicating the relationship between moisture content and water activity increased rapidly. Overall, a logarithmic increase was observed with a significantly high coefficient of determination ($R^2 = 0.97$), as shown in Fig. 2. This adsorption isotherm pattern in the 0.8–1.0 range of aw agrees well with that of previous

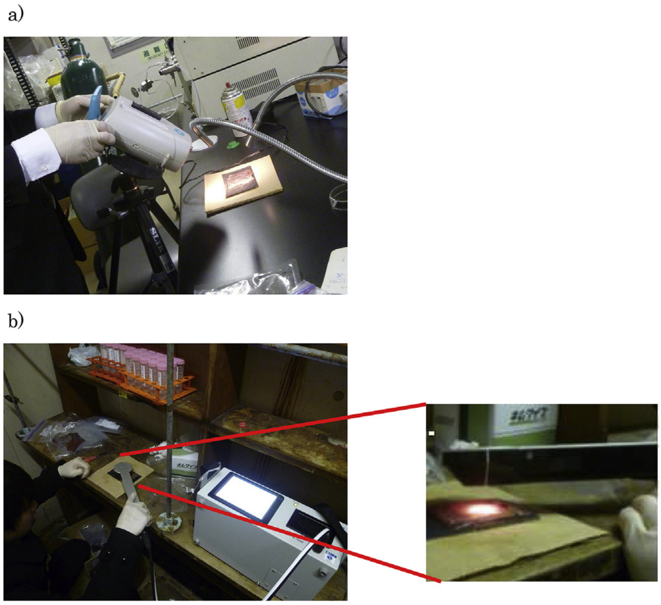

Fig. 1. Schematic photograph of (a) visible and (b) near infrared (NIR) spectra measurements. The right side of (b) is the scaled-up photo of (b).