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Combining the genetic algorithm and successive projection algorithm for the selection of feature wavelengths to evaluate exudative characteristics in frozen–thawed fish muscle

Jun-Hu Cheng [a], Da-Wen Sun [a,b,*], Hongbin Pu [a]

[a] College of Light Industry and Food Sciences, South China University of Technology, Guangzhou 510641, China
[b] Food Refrigeration and Computerized Food Technology, Agriculture and Food Science Centre, University College Dublin, National University of Ireland, Belfield, Dublin 4, Ireland

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ABSTRACT

The potential use of feature wavelengths for predicting drip loss in grass carp fish, as affected by being frozen at −20 °C for 24 h and thawed at 4 °C for 1, 2, 4, and 6 days, was investigated. Hyperspectral images of frozen–thawed fish were obtained and their corresponding spectra were extracted. Least-squares support vector machine and multiple linear regression (MLR) models were established using five key wavelengths, selected by combining a genetic algorithm and successive projections algorithm, and this showed satisfactory performance in drip loss prediction. The MLR model with a determination coefficient of prediction (R_P^2) of 0.9258, and lower root mean square error estimated by a prediction (RMSEP) of 1.12%, was applied to transfer each pixel of the image and generate the distribution maps of exudation changes. The results confirmed that it is feasible to identify the feature wavelengths using variable selection methods and chemometric analysis for developing on-line multispectral imaging.

1. Introduction

Fish is highly perishable, therefore preservation techniques and methods such as cooling (Desmond, Kenny, Ward, & Sun, 2000; Sun & Wang, 2000; Wang & Sun, 2002a, 2002b, 2004; Zheng & Sun, 2004), freezing (Kiani & Sun, 2011) and drying (Cui, Sun, Chen, & Sun, 2008; Delgado & Sun, 2002) are used to ensure product quality and safety. In particular, compared with terrestrial animals, fish is more highly susceptible to muscle deterioration during post-mortem storage due to a series of variations in biochemical, physicochemical and microbial activity, resulting in adenosine triphosphate (ATP) degradation, protein decomposition, lipid oxidation and textural cracking (Cheng, Sun, Han, & Zeng, 2014; Cheng, Sun, Zeng, & Liu, 2013; Liu, Liang, Xia, Regenstein, & Zhou, 2013). These changes influence greatly the quality of fish muscle, especially its freshness, which directly affects the purchase intention of consumers and the need of the market (Alishahi & Aïder, 2012; Cheng et al., 2013). Therefore, in order to preserve the fish and maintain the fish muscle quality, freezing is a common practice method in the food sector for extending the shelf life of aquatic products. Freezing has been broadly applied in the fishery processing industry, since it is one of the best ways for sustaining the inherent nutritional and sensory quality for a long period of time, restraining the microbial growth and spoilage, and diminishing the biochemical changes before consumption (Costa et al., 2011; Foegeding, Lanier, & Hultin, 1996).

However, frozen–thawed products can suffer from quality loss including water loss, lipid oxidation and undesirable texture and flavor of fish during marketing and production (Ozogul et al., 2011). During the freezing process, some of the water freezes out, and the concentration of solutes in unfrozen solutions increases. This phenomenon may induce the increase of enzymatic activity, degradation of the muscle proteins and structural damage of membranes, which can lead to the increase of drip loss (DL), the decrease of water holding capacity (WHC) (Cheng & Sun, 2008) and textural changes (Foegeding et al., 1996). Among these changes, The DL of food products is a significant quality parameter that impacts both profitability and quality during transport and storage. It is not only appealing to consumers in that it might influence juiciness, flavor, appearance and texture, but also of great economic importance to the industry as fish is sold by weight (Huff-Lonergan & Lonergan, 2005). Moreover, DL also entails the loss of water soluble nutritional compounds such as minerals and water-soluble and sarcoplasmic proteins, supplying a

* Corresponding author at: Food Refrigeration and Computerized Food Technology, Agriculture and Food Science Centre, University College Dublin, National University of Ireland, Belfield, Dublin 4, Ireland.
E-mail address: dawen.sun@ucd.ie (D.-W. Sun).
URLs: http://www.ucd.ie/refrig, http://www.ucd.ie/sun (D.-W. Sun).

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nutritious medium for microbial activity. DL is usually expressed as a percentage of the initial weight of the product (Huff-Lonergan & Lonergan, 2005). Duun and Rustad (2008) reported the quality changes of superchilled, vacuum packed Atlantic salmon fillets stored at −1.4 °C and −3.6 °C, and showed that DL was not a major problem in superchilled salmon fillet. Similar results were also observed by Olsson, Ofstad, Lødemel, and Olsen (2003), who found that there was no significant difference in DL between 1 and 14 days of storage for the superchilled Atlantic salmon muscle samples, but a significant increase in DL was observed at day 21. In another study, Liu et al. (2013) reported the DL change of grass carp (*Ctenopharyngodon idella*) fillets stored at −3 °C and 0 °C, and indicated that a rapid increase in DL was observed for fish fillets stored at −3 °C for 3 days and also for those stored at 0 °C for 1 day. These investigations have confirmed that DL is an effective way to evaluate the exudative characteristics of frozen fish muscle. Unfortunately, the current DL measurement methods are commonly time-consuming, tedious, contaminative and consequently unsuitable for on-line industrial applications.

Currently, there is no commercial on-line measurement system for evaluation of exudative characteristics of frozen–thawed fish muscle. To meet the demands of an increasingly discerning consumer, it is necessary to improve quality loss control methodologies for the assessment of fish quality. For this reason, the fish processing industry desires non-contact, non-destructive, rapid and efficient analytical techniques to guarantee quality, safety and authenticity. Recently, hyperspectral imaging (HSI) has been introduced to integrate both spectroscopic and imaging or computer vision (Costa et al., 2011; Jackman, Sun, Du, & Allen, 2009; Sun, 2004; Wang & Sun, 2002) techniques into one system for providing both spectral and spatial information simultaneously. The obtained hyperspectral images usually contain a huge amount of information in a three-dimensional (3D) form called a "hypercube", which can be analyzed to ascertain the physical and chemical features of the tested object in preference to the traditional machine vision or spectroscopy techniques (Barbin, ElMasry, Sun, & Allen, 2012; ElMasry, Barbin, Sun, & Allen, 2012; ElMasry, Kamruzzaman, Sun, & Allen, 2012; Feng & Sun, 2012; Kamruzzaman, ElMasry, Sun, & Allen, 2012; Lorente et al., 2012; Wu & Sun, 2013; Wu, Sun, & He, 2012). In the past three years, HSI coupled with chemometrics analysis has received special attention for quality and safety assessment of fish and seafoods (Cheng et al., 2013; Cheng & Sun, 2014). Also, it has been successfully implemented for evaluating the freshness of rainbow trout (Khojastehnazhand et al., 2014) and expired vacuum-packed smoked salmon (Ivorra et al., 2013), and for predicting the moisture content (He, Wu, & Sun, 2013; Zhu, Zhang, Shao, He, & Ngadi, 2014) of salmon. As to the DL measurement, Qiao et al. (2007) introduced a visible and near infrared HSI (400–1000 nm) and Barbin, ElMasry, Sun, and Allen (2012) developed a near infrared HSI system (900–1700 nm) to predict the DL value in pork meat, and He, Wu, and Sun (2014) used another visible and near infrared HSI system to measure DL in farmed Atlantic salmon fillet. All of these studies showed relatively poor performance in the prediction of DL. Thus, it is difficult to develop on-line detection systems due to the inferior predictive performance and lower reliability and accuracy of the prediction model. In addition, the above studies did not involve any frozen–thawed process that is commonly used in the meat processing industry and is one of the most important factors affecting the drip loss.

Therefore, in order to improve the prediction capability for further study on on-line industrial application, the main objective of this investigation was to select several of the most influential wavelengths using a genetic algorithm and successive projection algorithm and to develop on-line multispectral imaging for evaluation of exudative characteristics in frozen–thawed grass carp fish muscle based on DL determination in tandem with least-squares support vector machine (LS-SVM) and multiple linear regression (MLR).

2. Material and methods

2.1. Fish samples preparation

A total of thirty fresh grass carp fish with an approximate weight of 1.5 kg, and from a similar feeding environment in the freshwater aquaculture ponds, were purchased in a local market in Guangzhou, China, and transported directly to the laboratory alive, in water in a big plastic bucket, within 15 min. Upon arrival, the fish were stunned by a sharp blow to the head with a wooden stick and then the gills were cut. The internal organs were discarded at the same time with bloodletting from the fish belly area. Then they were instantly beheaded, skinned, filleted and washed with cold water. In order to obtain more fish muscle samples, the fresh fillets were immediately subsampled into a cuboid shape with analogous size of 3.0 cm × 3.0 cm × 1.0 cm (length × width × thickness). As a result, 240 subsamples of fish fillet were obtained from different locations of examined fish fillets and weighed before being packaged in plastic bags for frozen storage. All the packaged subsamples were frozen at −20 °C for 24 h in a cryogenic refrigerator (Haier Company, Qingdao, China), and then they were randomly divided into four groups and thawed at 4 °C for 1, 2, 4, and 6 days, respectively. Consequently, each group consisted of 60 frozen–thawed subsamples for further analysis. From the 240 subsamples, two thirds of the samples (n = 160) from each group were used to build the calibration set (training set) and the remaining one third of the samples (n = 80) from each group was used to create the prediction set (testing set).

2.2. Drip loss reference measurement

Each fish subsample was weighed before freezing and thawing. For the quantification of DL, the fish subsample was removed from the plastic bag after thawing at 4 °C for 1–6 days and the remaining liquid in the bag was also weighed. The calculation of the drip loss was based on the initial weight of sample after thawing and estimated gravimetrically using the formula below:

$$\mathrm{DL}\ (\%) = \frac{W_0 - W_1}{W_0} \times 100\% \quad (1)$$

where W_0 is the initial weight (g) of fish subsample before storage and W_1 is the weight (g) of the fish subsample after frozen–thawed storage. Mean values were calculated from three triplicates.

2.3. Visible and near infrared HSI measurement

2.3.1. HSI system

A laboratory reflectance visible and near infrared HSI system was used in this study as shown in Fig. 1. The system consisted of an imaging spectrograph, a charge-coupled device (CCD) camera, an illumination system and a computer control system. Detailed descriptions of the system is available in the literature (Cheng, Sun, Pu, Wang, & Chen, 2015). In this study, the actual working spectral range of this HSI system was 308–1105 nm and there was a spectral increment of about 1.58 nm between the contiguous bands, thus yielding a total of 501 bands. However, due to the low signal to noise ratio in the spectral range of 308–399 nm and 1001–1105 nm, some bands were removed and the spectral range of 400–1000 nm with a total of 381 wavebands (variables) was considered effective and used for further analysis.