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Developing hyperspectral prediction model for investigating dehydrating and rehydrating mass changes of vacuum freeze dried grass carp fillets

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ABSTRACT

Vacuum freeze drying is a technique for producing dried food products with superior quality. The current study used Vis-NIR (400–1000 nm) hyperspectral imaging in tandem with chemometric analysis to investigate dehydrating and rehydrating mass changes of vacuum freeze dried grass carp fillets (*Ctenopharyngodon idella*). Mean, median and mode spectra of grass carp fillet samples were extracted and compared to build the best partial least squares regression (PLSR) model for predicting the sample dehydrating mass loss percentage and rehydrating mass gain percentage, together with spectral pre-treatments including multiplicative scatter correction (MSC), standard normal variate (SNV) and Savitzky–Golay (SG) smoothing. The effects of spectral pre-treatments and selection of wavelengths on the performance of the developed PLSR models were evaluated, and the PLSR model based on simplified mean spectra pre-treated by SG-smoothing (dehydration: $R_p^2 = 0.9325$, RMSEP = 5.34%; rehydration: $R_p^2 = 0.8278$, RMSEP = 9.79%) was determined as the best prediction model, which was finally used to develop pixel wise visualization of the values of mass loss and gain percentages within the samples.

1. Introduction

Like cooling (Sun and Hu, 2003; Wang and Sun, 2002; Sun and Wang, 2000; Sun, 1997; McDonald et al., 2000; Sun and Brosnan, 1999; Zheng and Sun, 2004; Wang et al., 2004) and freezing (Kiani et al., 2011; Ma et al., 2015; Xie et al., 2015, 2016; Cheng et al., 2016a,b, 2017; Pu et al., 2015a), drying (Cui et al., 2008b; Yang et al., 2017; Pu et al., 2016) is a common method for keeping the quality of agricultural and food products. Conventional drying methods, such as hot air or solar drying, to some extent result in serious changes in product quality due to exposure to high temperature and oxygen presence, on the other hand, vacuum freeze drying can produce high quality food products with minimal transformations in texture, flavour, rehydration ability and chemical compositions. In essence, vacuum freeze drying is a process of sublimation after water is frozen to ice in food products, which has been widely used in the food industry for drying fruits (Asami et al., 2003; De Beer et al., 2009; Romero-Torres et al., 2007), vegetables (Chen et al., 2016; Cui et al., 2008a; George and Datta, 2002; Que et al., 2008; Pei et al., 2014a,b), coffee (Andriot et al., 2004; Fissore et al., 2014; Suwelack and Kunke, 2002), milk (Song et al., 2002; Wang et al., 2005), meat (Babić

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et al., 2009; Sun et al., 2001) and other high-value food products. Grass carp (*Ctenopharyngodon idella*) is consumed as a nutritional food in a large quantity. On the other hand, due to the perishability and vulnerability of fish muscle, vacuum freeze drying can dehydrate the fillets to obtain high-quality dried products with good nutritional quality, texture, flavour, colour, and minimal shrinkage (Marques et al., 2006).

For monitoring the process of freeze drying, Raman or near infrared spectroscopy (NIRS) has been used to exactly recognize the onset of water-to-ice conversion, crystallization and polymorphic transformations of mannitol, and solid state characterization of end products (De Beer et al., 2009; Romero-Torres et al., 2007). For evaluating the quality of food product dehydrated by vacuum freeze drying, Viljoen et al. (2005) employed NIRS to determine the contents of ash, dry matter, crude protein and fat of freeze—dried ostrich meat and the best correlation coefficient of 0.99 using partial least-square regression (PLSR) method was achieved. Although NIRS is rapid, accurate and convenient, it cannot generate the composition distribution map or adequately screen the details of vacuum freeze drying including possible drying non-uniformity or un-thoroughness. By integrating spectroscopy and computer vision (Jackman et al., 2009, 2011; Du and Sun, 2005; Sun and Brosnan, 2003) or imaging into one system, in recent years, hyperspectral imaging (HSI) has been widely investigated in the food industry for providing component information by spectral analysis and producing visualization maps by image processing (Sun, 2010; Ma et al., 2016; Cheng and Sun, 2014; Cheng and Sun, 2015a,b; Kamruzzaman et al., 2015, 2013; Lorente et al., 2012; ElMasry et al., 2012a; ElMasry et al., 2013; Liu et al., 2014; Barbin et al., 2013; Feng et al., 2013; Wu and Sun, 2013; Xiong et al., 2015; Cheng et al., 2015, 2016; Pu et al., 2015b).

To the best of our knowledge, there is no report on using HSI for monitoring the quality of dehydrated fish slices as affected by vacuum freeze drying. In terms of data processing, mean, median and mode have been used to delineate the central tendency of a group of data in statistics (Runnenburg, 1978). In order to represent the spectral characteristics within one sample from multi-perspectives, mean, median and mode spectral calculations can thus be attempted to manipulate the extracted spectral data of each pixel within the same sample, which should provide alternative strategies for model development and improvement along with spectral pre-processing methods including multiplicative scatter correction (MSC), standard normal variate (SNV) and Savitzky–Golay (SG)-smoothing.

Therefore, the objective of this work was to use HSI (400–1000 nm) to predict the dehydrating and rehydrating properties of grass carp (*C. idella*) fillets with vacuum freeze drying treatments. Particularly, mean, median and mode spectral features with or without pre-treatments were compared to determine the ability in improving the accuracy of predictive PLSR models. Fig. 1 shows the experimental and data processing procedure used in the current study.

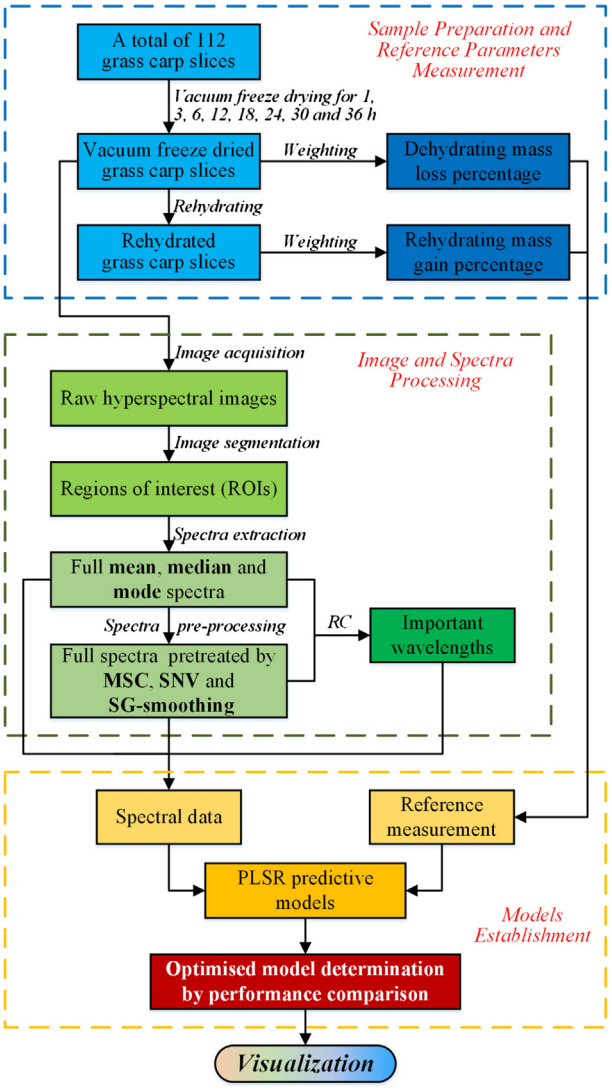

Fig. 1 – Flowchart of the experimental and data processing procedure.

2. Materials and methods

2.1. Sample preparation

A total of fourteen fresh grass carps (*C. idellus*) were purchased from a local Wal-Mart supermarket in Guangzhou, China in seven batches with an average weight of 1.97 kg and standard deviation of 0.32 kg. After being transported to the laboratory alive in water, the fresh grass carps were slaughtered by stunning the head with a wooden stick, beheaded, gutted, skinned, and filleted and then washed with cold water and slightly wiped up by filter paper (Cheng et al., 2014). 112 fish fillets with parallel size of 4.0 cm × 6.0 cm × 0.5 cm (length × width × thickness) were obtained from different locations of the fish samples and then they were equally allocated to seven groups. Sixteen samples in each group were frozen at − 80 °C for 12 h until the average core temperature of all the samples reached −75 °C. Then the samples were subjected to be dehydrated for 3, 6, 12, 18, 24, 30 and 36 h, respectively, at a condenser temperature of −56 °C in a vacuum freeze drier (Scientz-18N, Ningbo Xinzhi Biotech Co., Ltd.) with a vacuum degree of 10 Pa. Seven dehydrating and rehydrating levels were thus created each with sixteen parallel but slightly fluctuant values in order to establish accurate and convincing predictive models. For each batch, sixteen samples were obtained from the drier and then preserved in a desiccator temporarily for the subsequent spectral and chemical analysis.

2.2. Dehydrating and rehydrating experiments

After wiping out the surface water of the fresh grass carp slices, the samples were frozen at −80 °C and then dehydrated in the vacuum freeze drier for different periods. In order to measure the water loss during the drying process and the ability of the dried samples to rehydrate, the percentages of mass loss and mass gain during dehydrating and rehydrating were evaluated. For the dehydrating process, the initial and final masses were measured and the mass loss percentage L_d was determined by,

$$L_d = \frac{m_f - m_d}{m_f} \quad (1)$$