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Non-destructive prediction of soluble solids content of pear based on fruit surface feature classification and multivariate regression analysis

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ABSTRACT

Improving the prediction accuracy of SSC is the unremitting pursuit in the field of nondestructive optics. The Vis/NIR transmission spectra of 'Korla' pear were collected with a portable spectrometer instrument developed by ourselves. In order to study the effects of fruit surface feature such as peel color on determination of SSC and classification of surface locations, three types of SSC prediction models (separate location model, global locations model and average spectra model) and four types of surface location classification models (spectra regions: 550–950, 550–780, 780–950 and 550–700 nm) were built based on the full wavelengths (FWs) and effective wavelengths (EWs), respectively. Results showed that the prediction model of EWs-separate location achieved a best result, the correlation coefficient of prediction set (R_{pre}) were 0.9408 and 0.9463 for sunlit and shaded side samples, respectively, meanwhile, the classification model based on the 68 EWs selected from 550 to 950 nm achieved an optimal result with the correct classification rate of 97.78% and 96.67% in calibration and prediction sets, respectively. Overall mentioned results above illustrated the fruit surface feature was sensitive to the models of SSC prediction and fruit location classification. Therefore, a compensation model of SSC prediction that is robust and accurate, as well as insensitive to fruit surface feature was built by combining the EWs-classification model with EWs-separate location prediction model, the R_{pre} and root mean square error of prediction were 0.9368 and 0.5256 °Brix, respectively. In addition, the EWs-global locations model exhibited a negligible effect on the surface feature, although its prediction accuracy had a little inferior to the optimal compensation model. Hence, a complex compensation model with higher prediction accuracy of SSC showed a considerable potential for portable spectrometer instrument.

1. Introduction

'Korla' pear is a famous fruit that mainly cultivated in Xinjiang province, China. This fruit attracts many consumers for its sweet and refreshing and has been exported to many countries, such as Southeast Asia, Canada. Consumers' expectation for fruit quality have been steadily increasing over the last decades, so the fruit should be nutritious and also have appropriate texture and taste to meet consumers' demands [1]. Soluble solids content (SSC) is one of the most important internal properties because it is a key parameter for assessing fruit maturity and harvest time [2], and it also could provide valuable information for commercial decision making [3]. Traditionally, standard methods for SSC measurement are mostly destructive, inefficient, or time-consuming. They just can be applied to small groups of samples, and are not suitable for application in real-time determination. Hence, continuous monitoring and evaluations of links amongst recorded spectra data and standard parameters of quality such as SSC are fundamentally important when putting nondestructive optical methods into practice.

Fast optical techniques such as visual and near-infrared (Vis/NIR) spectroscopy are playing a prominent role in process analysis. The physical and chemical information of samples could be recorded into the Vis/NIR spectrum for the absorption of C–H and N–H molecular bonds in compounds. The potential to measure quality components non-destructively, online and quickly makes Vis/NIR spectroscopy an interesting alternative to classical (frequently destructive) measurement methods [4]. Numerous studies have been carried out for non-destructive estimation of the SSC of fruits [5]. However, high accuracy prediction for SSC using spectroscopy technology is still a challenge due to the high variety of fruit surface color, the spectrum measurement

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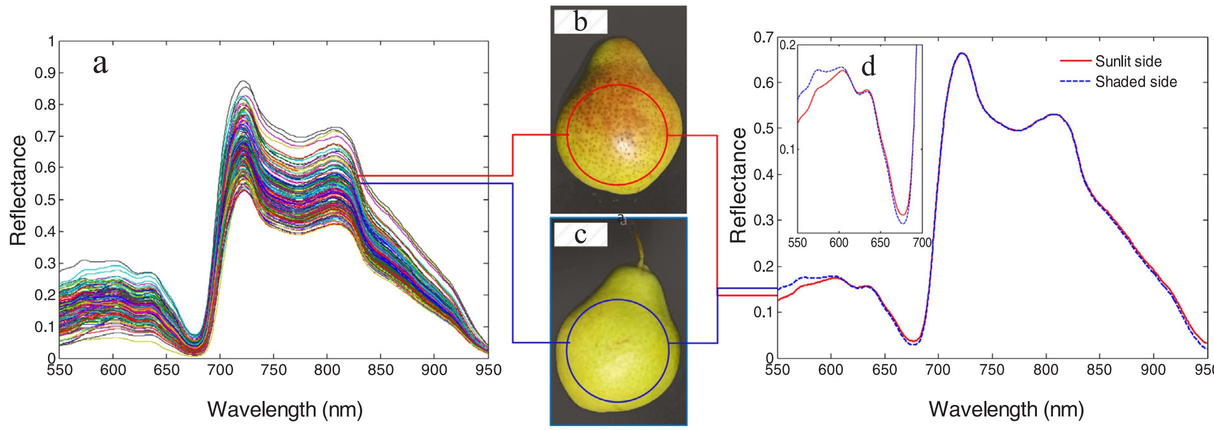

Fig. 1. The Vis/NIR spectra of sunlit and shaded side samples. (a) Raw spectra. (b) Sunlit sample spectra. (c) Shaded sample spectra. (d) Average spectra.

position on fruit, as well as the adaptability of the prediction model. To improve the prediction accuracy of SSC of apple, Guo et al. [6] established a compensation model combined the NIR spectra with apple surface color index, the prediction result had a significant improvement after the peel color index participated in regress model. Fan et al. [7] found that the prediction accuracy of SSC could be affected by the spectrum measurement position on apple surface, the global prediction model (contain stem, equator and calyx positions) was well suited to control the prediction accuracy of the calibration model for SSC with regardless to the variation of spectrum measurement position. Cayuela [8] developed three calibration models for SSC measurement based on different fruit sets. The first calibration was performed with four measures by spectrum, acquired at four 90° equatorial positions, whereas the second and third calibrations were obtained with two 180° equatorial measures by spectrum. Although the prediction accuracy obtained was satisfied, four measures or two measures increase the data acquiring and analyzing time and decrease the efficiency of the algorithm. Fan et al. [9] built a combined prediction model of SSC using the reflectance spectra and texture features of apple, the result improved compared with the spectra data used alone. Although these methods enable improve the prediction accuracy of SSC, the effect of fruit surface feature such as peel color on the SSC prediction model remains unknown, and the compensation model for SSC prediction that combining fruit surface feature classification with multivariate analysis are yet to be investigated.

Light plays a critical role in surface coloration for many fruits, such as pear and apple. In agriculture planting technology, fruit bagging is one of the key methods for planting high quality fruit, bagging could significantly decrease the diseases and insect pests at growing period, removing the bag is helpful for surface coloration at maturity period. Researches also have shown that light quality and quantity have effects on fruit quality during their growing and ripening stage. Light and shade can influence the activities of sucrose metabolizing enzymes, tissue development, as well as the expression of sucrose synthase-encoding genes of fruit, thus they have effects on fruit attributes and sugar metabolism [10]. Pigment is one of the most important compositions in peel components, which is responsible for the fruit surface color. Obtaining relationships between spectra data and standard parameters of quality or maturity is only possible to the extent to which those attributes relate to the pigment changes inherent in fruit reflectance or transmission spectra [11]. The content of chlorophylls, anthocyanins and carotenoids, and their proportion determine fruit peel appearance and color and serve as attributes of quality [12,13]. For 'Korla' pear, chlorophyll and anthocyanin determines its green and red color, respectively [14]. Hence, the 'Korla' pear often has two different types of surface color due to the light quality: the sunlit and shaded. Sunlit side could synthesize more anthocyanin and turn redder because it exposes to the light more strongly, whereas shaded side keep green always for lack of light radiation. In non-destructive measuring with optical method, fruits could be seen as optically dense or turbid materials, 96% of radiation is transmitted through the fruit peel into cellular structures where after interactions with different molecules and atoms, photons of specific wavelength are absorbed according to their energy levels [15]. Former researches have indicated that the pigments of fruit peel are principle absorption molecules with visible spectra of electromagnetic radiation [16]. Sadar et al. [17] found a prominent maxima determination coefficient for chlorophyll at 460–470 nm, in addition, strong correlations were reported to exist between anthocyanin content and the red color absorbance peak of 660–680 nm [18]. Therefore the intensity of reflectance spectra could be affected significantly by the peel of sunlit and shaded sides due to different pigments content. Additionally, it has been proven that chlorophyll is linked to quality indices such as soluble solid content and firmness, thus its content determined either destructively or nondestructively, was often used for quality evaluation and to predict the optimal harvest date of apples [19].

The overall aim of this study is to determine the applicability of transmitted spectra for estimating of SSC and distinguishing of fruit surface features. The objective was to (1) analyze the difference characteristic of effective wavelengths (EWs) selected from the sample sets of sunlit and shaded sides; (2) assess the influence of spectrum measurement location on determination of SSC using the Vis/NIR spectrometer instrument developed by ourselves; (3) build the identification model of surface location and quantify model of SSC based on full wavelengths (FWs) and EWs; (4) develop the optimal compensation model for SSC prediction by combining the surface feature classification model with the quantify model of SSC.

2. Materials and methods

2.1. Fruit samples

A total of 120 'Korla' pears enable clearly distinguish of sunlit and shaded sides (Fig. 1b and c), and free of visual defects (such as rots, cuts, scars, shrivel etc.) were purchased from a local fruit market in Beijing, China. All samples were individually washed, numbered and then stored in laboratory 24 h (temperature: 20 °C, relative humidity: 60%) before the experiment for making the samples reach room temperature and reducing the effect of pear temperature on the prediction accuracy [20]. In this study, each sample was cut into two parts (sunlit and shaded sides) along the vertical axis of stem-calyx at the position where enable distinguish the red and green color. Therefore, 120 sunlit and 120 shaded side samples were got.

In order to compare the performance of prediction models and reduce the interference factor from samples, as well as making the results more convincing, the sunlit and shaded side samples from the same one