Investigation of the spatial variation of total soluble solids in postharvest mulberry fruit

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Abstract

To better understand the ripening process of mulberry and find a suitable postharvest storage strategy, it is necessary to visualize the quality variation inside mulberry fruit. This study focuses on fast monitoring the Total soluble solids (TSS) variation inside postharvest mulberry fruit using hyperspectral imaging (HSI) technique. Mulberry fruits with different TSS contents were selected at different postharvest periods, and were stored in refrigeration and room temperature as control. During the storage, mulberry fruits were cut at longitudinal sections and hyperspectral images of treated and control fruit were obtained by a visible/near infrared (Vis/NIR) HSI system. When the spectral image acquisition was completed for each fruit, its reference TSS was determined immediately by a handheld refractometer. At last, a robust prediction model between the reflectance spectra of fruits and their TSS references were established using partial least square regression. Results showed that a good correlation was obtained between the reference TSS values and spectral information. The quantitative TSS distribution inside mulberry fruit was visualized. This study presents a rapid method of HSI for visualization of TSS distributions in fresh-cut mulberry fruit. To the best of our knowledge, this is the first study on using hyperspectral imaging to measure TSS distributions inside mulberry fruits. Hyperspectral imaging system supported by multivariate image analysis methods is a powerful tool in evaluating and visualizing the TSS distribution inside mulberry fruit at pixel level.

Background

The mulberry fruit (*Mours alba* L) is a multiple fruit, approximately 2 to 3 cm (one inch) long. It is the ripe fruit from mulberry tree (Morus sp.) native to China and now is planted in many different climates and zones (Ercisli and Orhan 2007). Related researches show that the mulberry fruit is rich in sugar, acid, and bioactive components such as vitamins, anthocyanins, flavonoids, polyphenols, (Du et al. 2008, Jiang and Nie, 2015). Total soluble solids (TSS) is an important parameter when we evaluate the quality of mulberry fruit. TSS is usually measured by a handheld refractor. However, this method of measurement only provides the value of the concentration of TSS and cannot give the detailed information about TSS distribution in the mulberry fruit. Therefore, to get the detailed information in the change of TSS during the postharvest period, the advanced technologies are needed to provide the distribution of TSS inside the mulberry fruit at the pixel level.

Hyperspectral imaging (HSI), like other spectral imaging, collects and processes information from across the electromagnetic spectrum, which not only can provide the spectral information of each pixel but also the image of the sample, so it has the dual advantages of image and spectrum. In recent years, Many researchers have applied this technology into the quality testing of agricultural products, such as the moisture content of mangoes (Pu and Sun, 2017), the firmness of apples (Mendoza et al., 2012), the sugariness and hardness of melons (Sun et al., 2016).In addition, due to the HSI technology can simultaneously provide the space and quantity information of sample, this means the internal quality of sample can be measured and the spatial distribution of a quality indicator can be presented at the same time.

As we all know, the TSS content in the mulberry is constantly changing during the pre-harvest or post-harvest maturation process and the distribution of TSS in mulberry fruit is heterogeneous, however, traditional chemical methods can just give the changes in the total content of TSS and not provide more detailed spatial information of quality variation in mulberry fruit. Hence, visualization of TSS in mulberry at the pixel level is of great significance for an in-depth understanding of mulberry ripening processes, determination of picking opportunities and identification of postharvest storage methods. The primary aim of the present study was to investigate the feasibility of HSI technique for providing more detailed information about the change of TSS in mulberry through visualization of TSS in the mulberry pulp at the pixel level. The outcome of this study shows that it is feasible to determine the quality of mulberry and TSS visualization inside mulberry pulp.

Methods

'Dashi' Mulberry fruit (*Morus australis Poir*.) were picked from a commercial mulberry garden in Nanxun, Zhejiang province, China, in2017. After harvest, mulberry fruit was immediately transformed to the laboratory, and 120 fruit of uniform maturity without disease and mechanical wounding were selected. At last, the 120 mulberry fruit was average divided into batches and then placed into two storage temperature namely normal temperature (27℃) and low temperature (4℃). Six points were considered,
0 day and 1 day (including 2 points, namely morning and afternoon) as the normal temperature stages and 2, 4, 6 days as the low temperature stages. 20 fruit were considered at each sampling stage. The mulberry samples were cut at longitudinal sections before acquiring the HIS images.

In this experiment, the hyperspectral image of mulberry samples was obtained by a hyperspectral imaging system with the cameras covering the spectral range of 890nm-1728nm. The hyperspectral imaging system use line-scanning to obtain the images, and the scanning mode is more efficient than point scanning. There were256 spectral bands (spectral variables) obtained. As the raw image obtained by the hyperspectral imaging system contain some detector signal rather than the actual reflectance spectra, the measured raw images were corrected using black and white reference images before further analysis. Specific process can refer the literature (Wu et al., 2012).A quantitative relationship should be built between the each pixel spectral information and the reference value of TSS to visualize the distribution of TSS in mulberry pulp. The extracted mean spectral data from all samples were arranged in a spectral matrix (X) as the independent variables, where the rows of the matrix represented the samples and the columns represented the spectral variables. After the TSS reference and the corresponding spectral information are obtained, the establishment of the model is an important step in this study. PLSR is a classic linear regression method. PLSR was carried out to perform calibration between spectral matrix (X)and the values of TSS (Y).All computations of model calibration and prediction were operated with Unscrambler 9.7 (CAMO PROCESS AS, Oslo, Norway) and Matlab 2015a software (The Mathworks, Inc., Natick, MA, USA). After model calibration, the distribution maps of TSS variation within the mulberry were generated based on the spectrum and the corresponding spatial position of every pixel.

Results

To establish the qualitative / quantitative relationship between the TSS value and the spectral data, the model calibration was applied for the calculation of the three sets of data based on the full range spectra, and the results are shown in Table 1.The performance of PLS is evaluated and compared according to the evaluation standard. The value of r_{val}, R^2_{val} and RMSECV respectively is 0.859, 0.671 and 0.691 in the model established using spectral data of room temperature sample. In the same way, the model of low temperature has the higher accuracy than the group of room temperature, and the value of r_{val}, R^2_{val} and RMSECV respectively is 0.877, 0.744 and 0.738. The combinative group has the best predictive accuracy, whose r_{val}, R^2_{val} and RMSECV respectively is 0.927, 0.853, 0.662. When we considered the performance of the model from the perspective of RPD and AB_RMSE, what can be seen is the room temperature group has the smallest value of AB_RMSE (0.041) and the combinative group has the highest value of RPD (2.614).

Table 1. Prediction results of total soluble solids (TSS) of mulberry samples by analyzing the full range spectra

Group	Modeling method	r_{cal}	R^2_{cal}	RMSEC	r_{val}	R^2_{val}	RMSECV	RPD	AB_RMSE
27℃	PLS	0.888	0.789	0.732	0.859	0.671	0.691	1.941	0.041
4℃	PLS	0.919	0.845	0.621	0.877	0.744	0.738	2.077	0.117
Combined	PLS	0.966	0.934	0.445	0.927	0.853	0.662	2.614	0.217

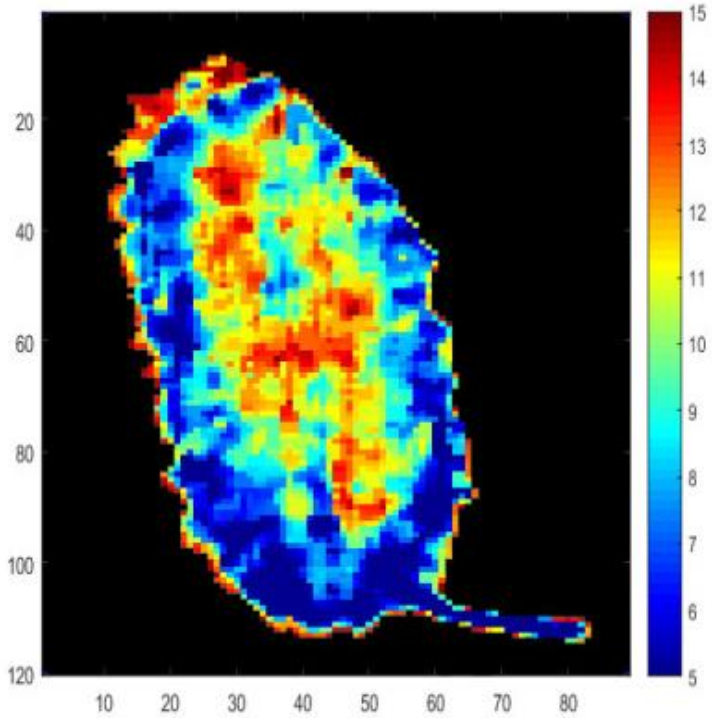

Figure 1. Examples of TSS distribution maps of mulberry pulp with different TSS contents generated based on hyperspectral imaging combined with chemometrics

Figure 1 was generated based on the combinative model. In the maps, the TSS value at each pixel were showed by the color, that is to say, different colors represent different TSS concentration values. The range of colors is from blue to red, and the corresponding TSS value is from 5 to 15 °Brix. In this study, all TSS values are in the range of 5 to 15, so the TSS distribution of mulberry can be displayed. In addition, we can found that the content of TSS in the edge of mulberry fruit was lower, and the content of TSS in the middle part was higher. The visualization map gives more detailed information which can help us to deeply understand the variance of TSS within mulberry fruit and provides a new way to study the influence of preharvest planting patterns and postharvest storage regimes to the quality of mulberry fruit.

Discussion

In this study, hyperspectral imaging technology and chemometrics method were applied to obtain the visual maps of TSS at each pixel in mulberry flesh. We take advantage of the feature that hyperspectral imaging technique can provides spectral information at each pixel, and then based on the relationship between the spectrum and the value of TSS established by PLS model to generate the map of TSS distribution in mulberry pulp. In general, RPD of over 2.5 corresponds to excellent prediction accuracy (Nicolaï et al. 2007). As we can see from the Table 1 that the best result belongs to the combination of the group of room temperature and the group of low temperature, in which the RPD is over 2.6 that indicate the model has a higher predictive accuracy.

Conclusion

TSS is an important quality indicator of mulberry, which even determines the taste and maturity of mulberry. Therefore, it is of great significance to visualize the content and distribution of TSS in mulberry. In this study, hyperspectral imaging was used to visualize the distribution of TSS in mulberry. We collected the hyperspectral image of mulberry longitudinal section at 890-1728 nm, and then measured the TSS content by a hand-held refractometer. Finally, the PLS model was used to generate the maps of TSS distribution at each pixel. The accuracy of the best model is 0.927, the value of RPD is 2.614, and with an AB_RMSE of 0.217. All of these indicate the model of PLS is accurate and reliable. Then we get the map of TSS distribution using the best model and more detailed information can be seen, these will help us further understand the ripening process of mulberry fruit and help us determine the optimal preharvest planting patterns and postharvest storage strategies.

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References

Du Q-Z, Zheng J-F, Xu Y 2008. Composition of anthocyanins in mulberry and their antioxidant activity. Journal of Food Composition and Analysis 21: 390–395.

Ercisli S, Orhan E 2007. Chemical composition of white (*Morus Alba*), red (*Morus rubra*), and black (*Morus nigra*) mulberry fruits. Food Chemistry 103: 1380–1384.

Jiang Y, Nie WJ 2015. Chemical properties in fruits of mulberry species from the Xinjiang province of China. Food Chemistry 174: 460.

Pu YY, Sun DW 2017. Combined hot-air and microwave-vacuum drying for improving drying uniformity of mango slices based on hyperspectral imaging visualisation of moisture content distribution. Biosystems Engineering 156: 108–119.

Sun M, Dong Z, Li L, Zheng W 2016. How to predict the sugariness and hardness of melons: a near-infrared hyperspectral imaging method. Food Chemistry 218: 413.

Wu D, Shi H, Wang S, He Y, Bao Y, Liu K 2012. Rapid prediction of moisture content of dehydrated prawns using online hyperspectral imaging system. Analytica Chimica Acta 726: 57.