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Development of a nondestructive measurement system for mango fruit using near infrared spectroscopy

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Abstract

Near infrared spectroscopy has been widely used for the evaluation of chemical components in food and agricultural products. In this study, a portable near infrared (NIR) spectrometer was developed to simultaneously evaluate the internal and external quality of tropical fruits. Mango fruits are grown in the southern part of Japan and have high economic value. In this region, sorting facilities are used to check the internal quality of each mango. However, most of the product is directly shipped to consumers, complicating quality assurance procedures. A portable NIR spectrometer is an affordable method for farmers to evaluate the internal and external quality of fruits. In this study, the soluble solid content (SSC) and skin color of mangoes (*Mangifera indica L. cv.* Irwin) were investigated using a portable NIR spectrometer. Calibration equations for SSC and skin color were developed using a partial least squares regression. The calibrations had a correlation coefficient of 0.90-0.95 in a wavelength range of 580–970 nm. Results showed that a portable NIR spectrometer is a useful and effective instrument to nondestructively analyze sugar content (as indicated by SSC) and skin color in mangoes.

Keywords: Mango fruits, Near infrared spectroscopy, Soluble solid content, Skin color

1. Introduction

Okinawa, in the southern region of Japan, is a major producer of tropical fruits, including mangoes and pineapples. Mango trees are often grown in greenhouses to avoid rainfall and diseases during their flowering season. Mango production has increased each year, with approximately 2000 tons shipped annually. The Irwin mango (*Mangifera indica L. cv.* Irwin) is one of the more common varieties, with a relatively high price ($18/kg). Therefore, the prefecture government promotes its production as an economic strategy. Mango fruits are typically harvested in July and most of the fruits are exported to the mainland of Japan by air, making quality inspection for each fruit very important.

Near infrared (NIR) spectroscopy has been widely used for the evaluation of chemical components in food and agricultural products [1-3]. In Japan, sorting facilities can use NIR spectroscopy to check the internal quality of the mango fruit. However, most of the fruit is directly shipped to consumers by individual farmers, complicating quality assurance procedures. Nondestructive instruments that are also small and affordable, such as an NIR spectrometer, would benefit many Japanese farmers.

Portable NIR spectrometers have been used to determine the quality of mangoes, oranges, and other fruits [4-6].

Previous research described the sugar content, acidity, firmness, and dry matter of fruits [7-10]. To date, no study has investigated a nondestructive measurement system for both SSC and skin color in Japanese Irwin mangoes. Moreover, there is currently no NIR spectrometer that is suitable for tropical agricultural products. The primary aim of this study was to develop and investigate the ability of portable NIR spectrometers to evaluate the quality of a tropical fruit. Using a portable NIR spectrometer, we report here the first stage in developing a calibration model and its accuracy in measuring the sugar content and skin color of mango fruit.

2. Materials and methods

2.1 Portable NIR spectrometer and spectra acquisition

Figure 1 shows an image of the portable NIR spectrometer (HKN Engineering, Co. Ltd., Japan) used in the current study. The instrument is convenient for on-site analysis because it does not have a motor or any moving parts, is lightweight (3.4 kg mass), and uses an optical fiber. The spectrometer can be operated with a Windows tablet. A log (1/R) spectrum of samples was acquired in the visible and NIR (Vis-NIR) regions (wavelength range from 570 to 1030 nm in 1 nm intervals).

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Figure 1 Portable NIR spectrophotometer

2.2 Samples

Mango fruits (*Mangifera indica* L. cv. Irwin) were obtained in Okinawa in 2015. Samples were taken from 122 fully ripe fruits and tested within 1 day of collection. The solid soluble content (SSC) and skin color were also measured after cutting and squeezing the samples.

2.3 Analysis of the quality of fruits by conventional methods

Vis-NIR spectra were obtained from five positions of the fruit. After scanning the spectra, skin color (CIE L*, a*, and b* values representing lightness, redness, and yellowness, respectively) were measured using a colorimeter (NF333, Nippon Denshoku Ind. Co. Ltd., Japan) at the same positions on the fruit. The sample was then cut into smaller pieces for juice extraction. The brix of the juice was immediately measured using a refractometer (PR101α, ATAGO Co. Ltd., Japan). The characteristics of the calibration and validation sample sets are presented in Table 1.

Table 1 Statistical characteristics of the calibration set for the quality of mango

	N	Average	Std.	Max	Min
SSC (°Brix)	576	13.7	1.4	7.8	18.3
L*	576	55.2	5.6	34.7	65.8
a*	575	23.3	6.3	−2.5	34.6
b*	576	42.3	10.4	10.2	63.7

N: number of spectra used in calibration
Std.: standard deviation

2.4 Data analysis

The measured spectra of each sample (absorbance and its second derivative) were saved to a file in CSV format. After obtaining the spectra, chemometric techniques were performed using the MATLAB program (MathWorks, Massachusetts, USA) to develop calibration models. Prior to calibration, a second derivative filter was applied to the Vis-NIR spectra to reduce differences in spectra caused by baseline shifts. The smoothing data point was set to 15. A partial least square (PLS) regression was employed to develop suitable calibration equations using the quality parameters and Vis-NIR spectra (600–1000 nm) values. The number of PLS factors was chosen from the minimized standard error of cross-validation. The accuracy of the model was evaluated using the coefficient of determination (R^2) and root mean square error of calibration (RMSEC). For cross-validation, the coefficient of determination (R^2_{cv}) and root mean square error of cross-validation (SECV) were calculated. RPD (ratio of standard deviation of reference data in cross-validation set to SECV) was also calculated to measure the capability of the calibration model to predict a particular parameter [6, 11].

3. Results and discussion

3.1 Vis-NIR spectra of the intact mango fruit

Vis-NIR spectra of the mango fruit samples were measured using the portable NIR spectrometer developed for use in this study, and calibration models were developed. The Vis-NIR spectra and second derivative spectra of 600–1000 nm wavelength regions are shown in Figure 2. Like many fruit samples, the spectra exhibit patterns similar to the NIR spectra of water. These results were consistent with those of a previous report in which the peak (near 970 nm) was assigned to the second overtone of the O–H stretching mode, and the other peak (approximately 670 nm) corresponded to that of chlorophyll. To develop a calibration model for SSC and L*a*b* values in these samples, second derivative spectra (shown on the right side of Figure 2) were used for PLS regression to reduce the baseline shift.

3.2 Calibration for SSC and skin colors of mango fruits

Sugar content and skin color are important quality measures for Irwin mangos. Mature Irwin mangos, the common variety cultivated in Okinawa, have red skin and are sweet because of their high sugar content. The sugar content of a fruit is a function of its SSC. So, the SSC of a fruit can be measured and its sugar content accurately estimated. Calibration models for the SSC and skin color, measured using the portable NIR spectrometer, were developed using PLS regression, and their accuracy was evaluated. The wavelength range selected affects the accuracy of the calibration in PLS regression [5].

The results were evaluated using calibration models with three different wavelength ranges (600–950, 600–800, and 800–950 nm) to provide the best result (data not shown). SSC calibration using 800–950 nm wavelengths showed the best results with a coefficient of determination of 0.77 and SECV of 0.69%. The results of the cross-validation for the SSC calibration model showed a coefficient of determination of 0.77 and a SECV value of 0.21%. The ratio of the standard deviation of the reference data in the cross-validation set to SECV (RPD) was 2.1. These results indicate that the calibration models can be used to determine SSC in mango fruit. Figure 3 shows a scatter plot of actual vs. predicted SSC of mango fruits.

For the skin color (L*a*b* values) calibration, the visible wavelength region (600–800 nm) was used. The calibration results are shown in Table 2. The SECV and RPD for the a* value were 2.89 and 2.97, respectively, with a correlation of determination in cross-validation (R^2cv) between the measured and predicted values of 0.78. The RPD for L* and b* values were 1.9 and 1.6, respectively, with a R^2cv between the measured and predicted values of 0.73 and 0.62, respectively. In general, the a* value is used as a color index (redness) and the L* value is used for lightness. Mature Irwin mango fruit is valued for its red and light skin color. Using a camera image, a study reported that it was possible to evaluate the skin color of berry fruit [12]. However, an

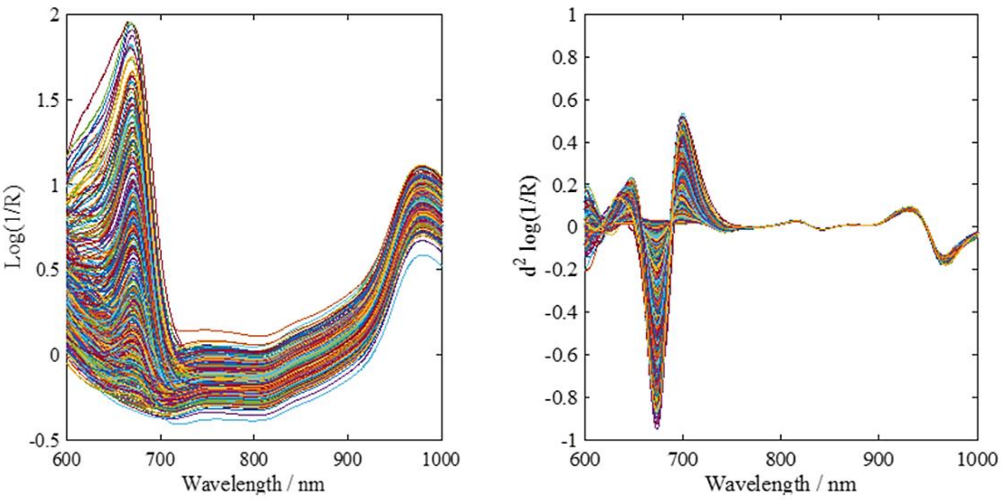

Figure 2 Visible-NIR spectra (log[1/R], left side) and second derivative spectra (d^2log[1/R], right side) of mango fruits measured with a portable NIR spectrometer.

evaluation of the skin color of mangoes has not been reported. Possibilities for SSC analysis of mangoes are given in some papers and with the accuracy (SEP) 0.57-1.97% [6, 9-11]. However, both the color and SSC analysis using a spectroscopic method are not reported. The NIR spectrometer developed for use in this study could simultaneously determine the internal and external quality of the fruit. Results indicate that the accuracy of the developed calibration models was adequate for practical purposes.

Table 2 Results of cross-validation for SSC and skin color of mango fruits

	nF	R^2	***RMSEC***	R^2cv	***SECV***	***RPD***
SSC	5	0.77	0.69	0.76	0.70	2.1
L*	7	0.75	2.80	0.73	2.88	1.9
a*	4	0.79	2.89	0.78	2.97	2.1
b*	5	0.64	6.26	0.62	6.42	1.6

nF: number of PLS factors used in the calibration model
RMSEC: root mean square error of calibration
R^2cv: coefficient of determination in cross-validation set
SECV: standard error of cross-validation
RPD: ratio of the standard deviation of reference data set to SECV

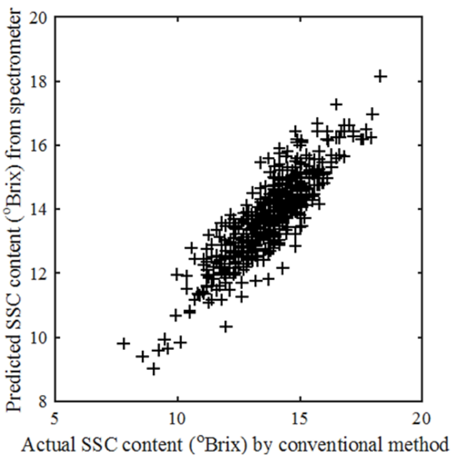

Figure 3 Predicted versus measured SSC of cross-validation set of Irwin mango.

3.3 Future work

The portable NIR spectrometer developed for use in this study measured mango SSC and skin color accurately. Future work could explore connecting this measurement system to an information system to enhance farm management. The NIR spectrometer could be useful to measure the internal and external quality of other varieties of mangos and other tropical produce, such as citrus, pineapple, and sugarcane.

4. Conclusions

A portable NIR spectrometer was developed for use in this study. The spectrometer operated in the Vis-NIR regions (570–1030 nm) and was found to be suitable for the evaluation of the internal and external quality of Irwin mangoes. NIR calibration models for SSC and skin color of Irwin mango were developed and evaluated. Results indicate that the portable NIR spectrometer is a useful tool for individual farmers for evaluating and providing high quality produce to consumers.

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