The methods of illumination and scanning for detecting internal disorders and quality of mangosteen by near infrared spectroscopy

S. Teerachaichayut,[a,b] W. Thanapase,[b] S. Kasemsumran,[b] K. Shigefuji,[c] K. Kiji,[c] Y. Nitta,[c] S. Saranwong[d] and S. Kawano[d]

[a]*King Mongkut's Institute of Technology Ladkrabang, Bangkok 10520 Thailand. E-mail: ktsontis@kmitl.ac.th*
[b]*Kasetsart Agricultural and Agro-Industrial Product Improvement Institute (KAPI), Kasetsart University, Bangkok 10300 Thailand*
[c]*Saika Technological Institute Foundation, Wakayama 640-8341 Japan*
[d]*National Food Research Institute, 2-1-12 Kannondai Tsukuba 305-8642 Japan*

Introduction

"Queen of the tropical fruits" is a name of mangosteen (*Garcinia mangostana* L.) because of its popular and delicious flavour, and fresh mangosteen has a good response from international markets. Physiological disorders in mangosteen called translucent flesh and gamboge as shown in Figure 1 make quality unacceptable for export.

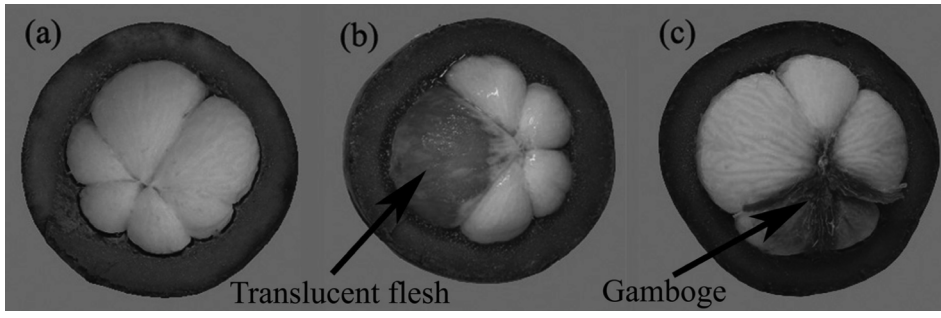

Figure 1. Normal mangosteen and mangosteens with physiological disorders (a) normal flesh (b) translucent flesh and (c) gamboge.

To control the quality, a reliable and highly accurate non-destructive inspecting technique for detection is required. At the laboratory in a previous research, the short wavelength-range near infrared (SW-NIR) spectrophotometer in transmittance mode was used to predict translucent flesh in intact mangosteens accurately.[1] An applied NIR sorting machine for detecting the internal quality of mangosteen was considered in the present research.

Materials and methods

Fruit samples

Mangosteen samples were transported to the laboratory and stored in an air-conditioned room under 25°C for 12 hours before individual measurements were made. Four types of NIR sorting machine were studied to allow measurements to be made in various positions, with different scanning time. The characteristics of each machine are shown in Figure 2.

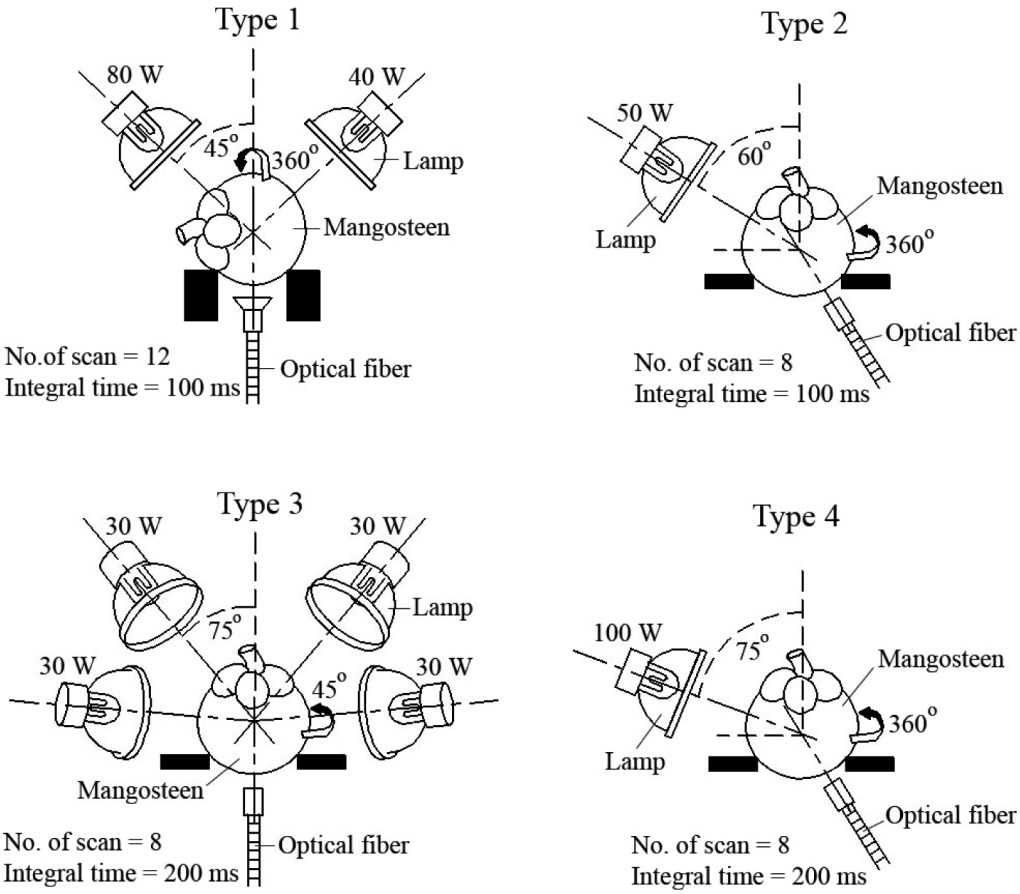

Figure 2. The online NIR sorting machines for detecting internal quality of mangosteen.

Then, the samples were cut open and photographed for selecting groups representative of normal flesh, translucent flesh and gamboge.

Data analysis

Maturity stage of the fruit was based on fruit skin colour. An index was developed as follows: stage 0 (immature) = yellowish white with light green, stage 1 = light greenish yellow with 5–50% scattered pink spots, stage 2 = light greenish yellow with 51–100% scattered pink spots, stage 3 = reddish pink, stage 4 = red to reddish purple, stage 5 = dark purple and stage 6 (fully mature) = purple black.[2] The levels of disorders were based on the area of internal defect, compared to the total flesh area from cut-open fruit. Degrees of internal condition for "translucent flesh" were: 1 = unclear (not sure to be "normal flesh" or "translucent flesh"), 2 = 10–40%, 3 = 50–100%; while for "gamboge": 1 = unclear (not sure to be "normal flesh" or "gamboge"), 2 = less than 10%, 3 = 10–40%, 4 = 50–100%. Samples were taken from a group of normal flesh ($N = 50$), a group of translucent flesh ($N = 50$) and a group of gamboge ($N = 50$) for classification analyses for each machine. The classification equations were developed using partial least squares regression (PLSR) indicating the dummy values of 0 for normal samples and 1 for disordered samples. Data were analysed by using "The Unscrambler" (CAMO, Oslo, Norway).

Results and discussion

The averaged spectra of samples were used for analysis in each group. The spectral pretreatment procedures were investigated so as to obtain the optimum result. We found that Type 3 and 4 illumination could provide spectra with better classification results compared with Type 1 and 2 (Figure 2). This could be explained by the position of lamp in relation to the position of calyxes.

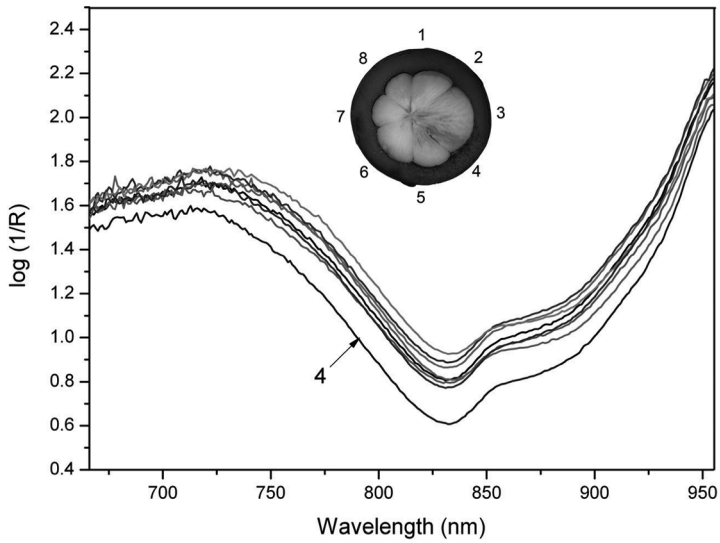

Figure 3. The spectrum of fruit portion 4 having translucent defect.

Table 1. The classification results of Type 4 for mangosteen classification using averaged spectra and individual spectra.

Disorder	Spectral pretreatment	averaged spectra		individual spectra	
		Normal	Disorder	Normal	Disorder
Translucent flesh	-	46/50(92%)	44/50(88%)	48/50(96%)	46/50(92%)
Gamboge	2nd derivative	43/50(86%)	38/50(76%)	44/50(88%)	39/50(78%)

Maturity stage: stage 4 and 5; Disorder level: level 2-3 for translucent flesh; level 3-4 for gamboge.

Due to the inconsistency of calyx size, sometime when the calyx was large, a part of the calyx would cover the light part from the lamp to the main body of the fruit, resulting in poor calibration results in Type 1 and Type 2. Another problem encountered with Type 1 was the instability of the fruit during sample rotation. Then, the calyx point up position was more suitable for measurement. The translucent flesh classification equations developed from NIR spectra measured by Type 3 and Type 4 had similar accuracy. However, for gamboge classification equations, the one developed from Type 3 could not provide satisfactory results while the Type 4 illumination was successful. Therefore, we used Type 4 for the investigations in this research.

The NIR spectra at the positions of disorders in the flesh were different from the spectra of fruits with normal-internal flesh inside as shown in Figure 3.

Individual spectra of each sample were considered likely to improve the classification. The classification results of sound flesh, translucent flesh and gamboge disorders calculated from individual spectra obtained better results when compared with the equations using average spectra (Table 1).

The individual NIR spectra of selected disordered samples were used to develop calibration equations of sound samples, translucent flesh samples (T), gamboge samples (G), translucent flesh + gamboge samples (TG) and all disordered samples (T + G + TG). A new set of 534 samples (269 of normal fruits, 39 of gamboge fruits, 111 of translucent fruits and 115 of translucent+gamboge fruits) was used to judge the predictive performance of the calibration equa-

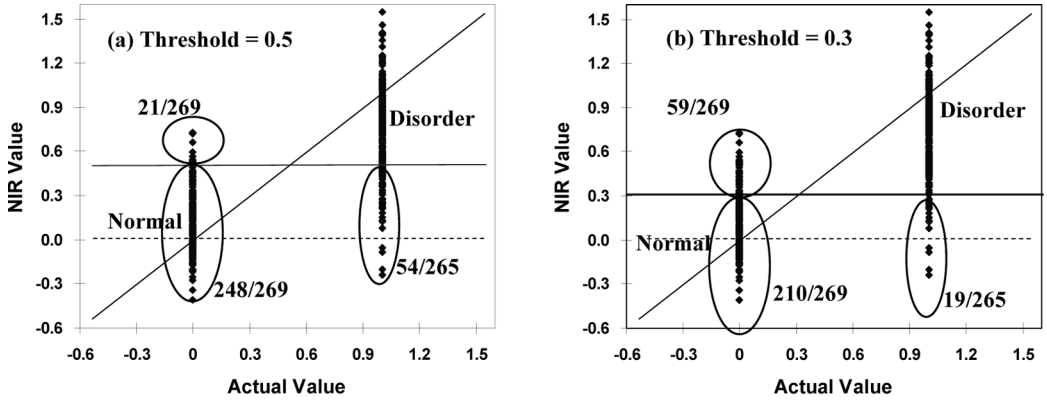

Figure 4. The classification results of an independent prediction set using the TG equation and two levels of threshold; (a) Threshold = 0.5; (b) Threshold = 0.3.

Table 2. Calibration statistics for evaluation the internal quality of intact mangosteen.

			Calibration set				Prediction set			
Unit	Wavelength (nm)	Factors	*N*	*R*	*SEC*	Bias	*N*	*R*	*SEP*	Bias
°Bx	665-955	8	150	0.90	0.73	-5.4×10^{-6}	50	0.90	0.72	–0.17

tions. The accuracy of each equation on the new set of mangosteen samples was examined. We found that the TG equation could work with better accuracy compared with the others. In these calculations, we used the threshold level of 0.5, which means those fruit with the predicted class value of 0.5 or more would be classified as disordered fruit, while samples classified as having values of less than 0.5 would be classified as normal fruit. The accuracy of prediction was 92% (248 fruits from a total of 269 fruits) for a normal group and 79% (211 fruits from a total of 265 fruits) for a disordered group as shown in Figure 4(a).

Changing the threshold level to 0.3 had no significant effect on the results of classification as shown in Figure 4(b).

It would be useful to use the NIR technique to determine sweetness in intact mangosteen, non-destructively, at the same time as the detection of internal disorder. Preliminary results, using the average spectra acquired from 200 normal fruits with Type 4 illumination showed that the PLS calibration results for Brix value of normal fruits could provide NIR spectra that were useful for prediction of Brix (Table 2).

Conclusion

The non-destructive NIR sorting machine described in this research, can be used to predict translucent flesh and gamboges disorders in mangosteen, but can possibly also be used to evaluate mangosteen sweetness. The accuracy of the prediction of disorders was improved when individual spectra of defected fruit were used instead of averaged spectra. Type 4 illumination obtained the best results. The research described has shown the potential of NIR sorting machine that could be used to evaluate the internal quality of mangosteen accurately. This seems to have the potential of improving the marketing of mangosteen in the future.

Acknowledgements

The authors would like to thank the Ministry of Agriculture, Forestry and Fisheries (MAFF), Japan for the financial supports, and to the Japan Society for Technology Innovation of Agriculture, Forestry and Fisheries (STAFF) for administrative support.

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