Non-destructive method for maturity assessment of Indonesian's mangoes by NIRS spectroscopy

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Abstract. Rapid and non-destructive method to determine maturity quality of mangoes accurately has played an increasing role in the fruits supply chain involving automation. Diffuse reflectance spectra (R) and absorbance spectra (Log 1/R) in the spectral range from 900 to 1400 nm were measured using NIRS spectroscopy at three different points of 257 Indonesians mangoes cultivar arumanis, manalagi, gadong, gincu and golek of different ripeness indices. Through principle component analysis (PCA) and cluster analysis (CA) of the absorbance and reflectance spectra, cultivars can be differed with an accuracy of 99.8%. Multiple linear regression was applied to develop calibration models from mangoes with soluble solid content ranged between 5.5 and 13.5 % Brix and firmness ranged between 0.25 and 4.50 kgf. Log 1 /R calibration model could assess the soluble solid content and firmness of the mangoes with higher accuracy than R model with the coefficient of determination of 0.96 and 0.93, respectively. Results showed that NIRS spectroscopy has the feasibility to be employed in the maturity measures of Indonesian's mangoes.
Keywords: NIRS spectroscopy, mango, total soluble solid, firmness, ripening.

Introduction

Some of Indonesian's mango varieties have economical value and potential to enter world markets. There is no standard method for determination of maturity of mango and experience plays an major role. In the big plantation, maturity determination involves trained labors and laboratory analysis. A long time and high cost required by conventional analytical method for assessment of fruit maturity cannot compensate the speed required by the trading of horticultural products. Lack of monitoring system to detect the maturity quality of mangoes may produce uneven quality. It is therefore crucial to adopt a non-destructive method in an easy operating application to assess the quality of mangoes, thus ensuring consistent supply of high quality mangoes for export.

NIRS has been used as a rapid and non-destructive technique for measuring the soluble solid content and firmness of several commodities in relation to ripening of fruits. Among the commodities are apple (Ying and Lia 2004), kiwifruit (McGlone *et al*. 1998), plum (Onda *et al*. 1995) and citrus (Zude *et al*. 2008). However, the application of NIRS in determination of fruit maturity is still lacking. In NIRS, the fruit is irradiated with light in the near infrared region (600 - 2500 nm). The spectra in this region contain abundant information reflecting the structure of molecules as well as attributes of fruits such as firmness, total soluble solids, etc. NIR absorption bands are produced when NIR radiation at specific frequencies resonates at the same frequency as the molecular bond in the test sample. This allow association of specific wavelength with a specific chemical bond vibration generating a specific spectrum that in turn is related to concentration of a specific component. The reflected or transmitted radiation by test samples is then mathematically compared with the spectra of reference samples that have been assayed previously by standardized wet chemistry or non-NIR methods.

This study reports the application of NIRS to assess the maturity of mangoes in term of total soluble solids and firmness as well as NIRS application for differentiation of mango cultivar by comparing the reflectance and absorbance spectra.

Materials and Methods

Sample preparation

The experiment used mangoes cultivar Arumanis, Manalagi, Gadong, Gincu and Golek grown in Aceh Province of Indonesia as sample material. During the experiment period, a total of 257 mangoes were harvested at different maturity stage of 90, 110 and 120 days after flowering. Mangoes were stored at temperature of 22^{o}C and relative humidity of 68% for two days before NIRS scanning for developing calibration model. For validation of the model, 50 mangoes from local market were bought and scanned with NIRS.

Spectral acquisition

Diffuse reflectance spectra (R) and absorbance spectra (Log 1/R) were collected over the wavelength range of 900 – 1400 nm using a NIR reflectance spectrometer (Shimadzu, Japan) equipped with tungsten halogen lamp as light source. Wavelength accuracy was based on scanning diffraction grating monochromatic of nominal bandwidth of 5 nm and a 0.5 nm step by averaging 100 scans. The NIR spectra were taken from the fruit surface at the stem-, middle and bud-ends part of the fruit. Periodic reference scan was performed every 30 min.

Firmness and soluble solid assessment

Firmness was assessed using rheometer (Kyowa CR-300, Japan). Firmness was defined as maximum force (kgf) required until tissue failure (Solatani *et al*., 2010) and measurements were undertaken at the middle part from stem end and distal end of the mango. To measure soluble solid content, mango flesh was pressed until juice extracted from the pulp. A drop of the juice was placed onto a digital refractometer (Atago N-100, Japan) to measure the soluble solid level in % Brix.

Data analysis. Principle Component Analysis (PCA) and Cluster Analysis (CA) were performed to differentiate each cultivar of mangoes based on its spectra. Calibration model was developed using stepwise multiple regressions procedure. Calibration model performance was assessed in terms of coefficient of correlation (r) and standard error of prediction.

Results and Discussion

Optical spectra of mango cultivars

The typical NIR spectra for five mango cultivars are presented in Figure 1. Through PCA and CA of reflectance and absorbance spectra, mangoes cultivars could be classified. First and second component of reflectance PCA explained 96.4 and 1.8 percent of the cultivars (Figure 2), respectively. Similar to reflectance spectra, first and second component of absorbance PCA explained 96.5 and 1.7 percent of mango cultivar. Both components of reflectance and absorbance spectra explained 98.1 and 98.2 percent of spectrum characteristic of mango cultivar. Gadong and Gincu as well as Manalagi and Arumanis have similarity in the reflectance and absorbance spectra, while spectra of Golek were isolated far from others.

Reflectance/absorbance NIR spectra of mango could be clustered into Arumanis and Golek cluster (Figure 3). Golek cultivar has different morphological and flavor characteristic compared to Arumanis group. Golek has long oval shape while the arumanis group round oval shape. Arumanis group is sweeter and has stronger aroma than Golek. Within Arumanis cluster, Gincu and Gadong was smaller in size around 150 – 200 gram and also sweeter with soluble solid content of 14 – 20 %Brix compared to Manalagi and Arumanis.

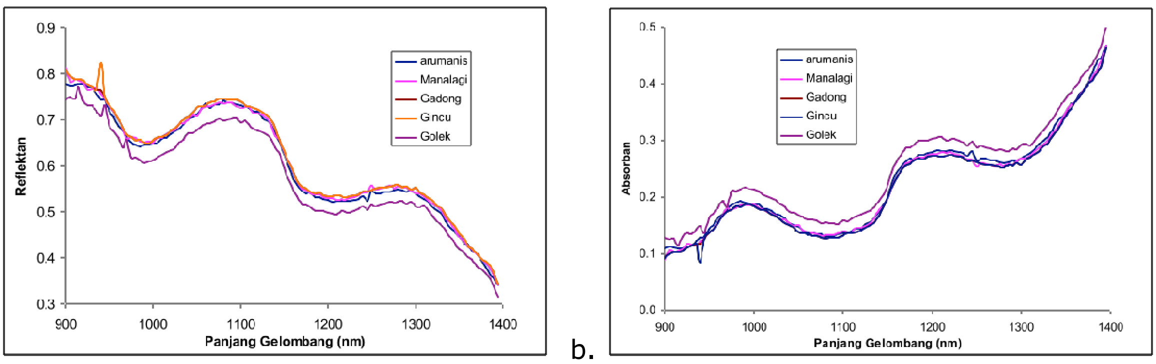
a.  b.

Figure 1. Reflectance (a) and absorbance (b) NIR spectra of different mango cultivars

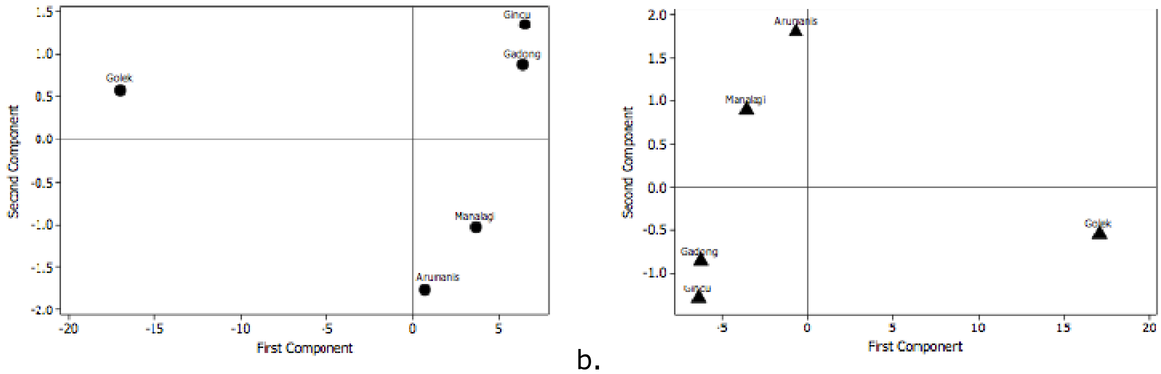


Figure 2. Principle component analysis of reflectance (a) and absorbance (b) NIR spectra of five mango cultivars

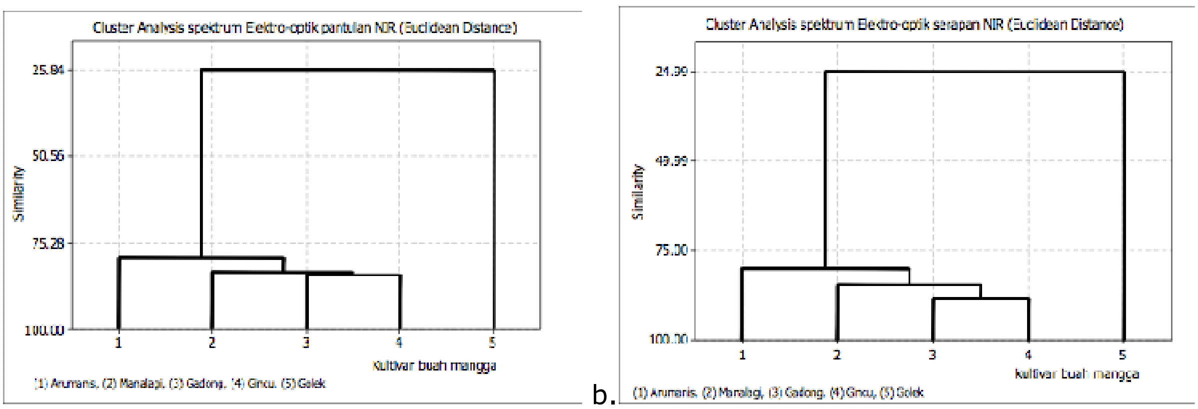


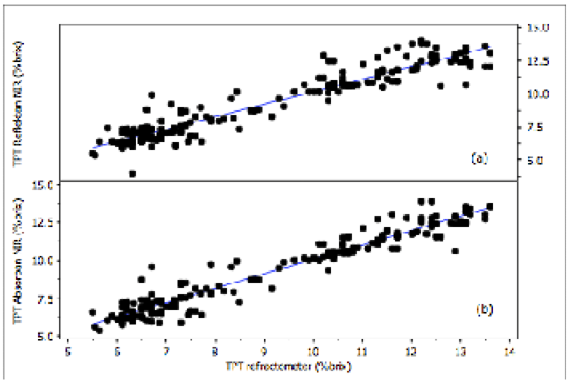
Figure 3. Cluster analysis of reflectance (a) and absorbance (b) NIR spectra of five mango cultivars

NIR assessment of soluble solid and firmness

Stepwise regression for calibration and prediction results for soluble solid and firmness are presented in Figure 4, Figure 5 and Table 1. The model for all maturity stages of mango indicated a high correlation between NIR and the measure SSC and Firmness value with r ranging from 0.91 to 0.94 for reflectance spectra and 0.93 to 0.96 for absorbance spectra with SEP ranged from 0.46 to 1.06. Absorbance spectra could assess soluble solid content and firmness better than reflectance spectra. This result supported Budiastra (1992) that was compared the NIR scanning using reflectance and absorbance spectra on Gadong cultivar of mango. The stepwise multiple regressions showed seven wavelengths of 910, 960, 1005, 1080, 1160, 1265 and 1295 nm that were significantly contributing in the calibration model for soluble solid content assessment. This study indicated broader range of NIR wavelength for soluble solid assessment.

Six wavelengths of 925, 945, 960, 1065, 1080 and 1090 nm were resulted for determination of calibration model for firmness assessment where the wavelength of 945 nm as the main contributor for the model. Similar results were found by McGlone *et al*. (1998) and Onda *et al*. (1995) that reported the contribution of the wavelength of 945 nm on the assessment of firmness in kiwi and plum. Siesler *et al*. (2002) reported that O-H bound of the pectin molecule is vibrating under exposure of wavelength of 945 nm. Pectin is a component of cell wall in the plant tissue and always related with texture and firmness of fruit.

Validation of the model against mangoes bought from market is presented in Figure 5 and Table 1. Validation results were also indicating a high correlation in range of 0.93 for reflectance spectra and 0.94 to 0.95 for absorbance spectra while the SEP ranged from 0.37 to 1.04. The accuracies of the developed calibration model for soluble solid and firmness were successfully validated where absorbance spectra have more accuracy for assessment of both soluble solid and firmness of mangoes.

a. 

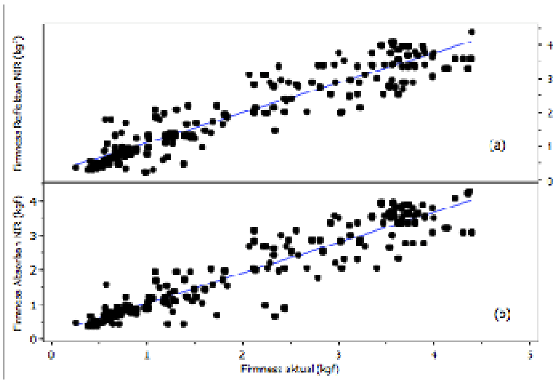
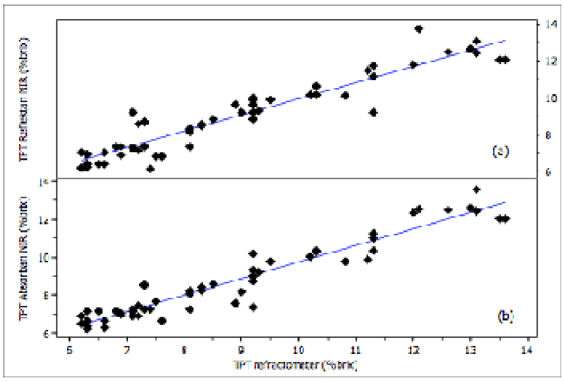
b. 

Figure 4. Calibration model of reflectance and absorbance spectra for determination of total soluble solids (a) and firmness (b) of mangoes

a. 

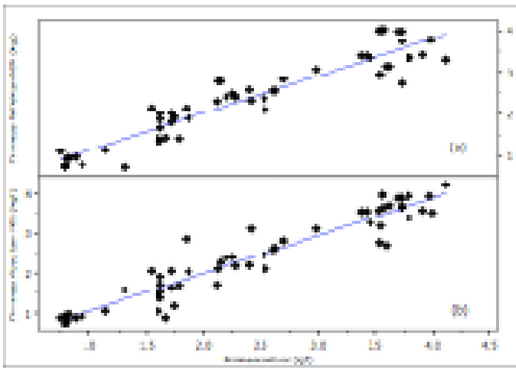
b. 

Figure 5. Non destructive NIRS prediction for soluble solid content (a) and firmness (b) in validation model of reflectance and absorbance spectra.

Table 1. Performance of calibration and prediction model for soluble solid and firmness of mangoes

Parameter	Soluble Solid				Firmness			
	Calibration		Validation		Calibration		Validation	
	Ref	Abs	Ref	Abs	Ref	Abs	Ref	Abs
r	0.94	0.96	0.93	0.96	0.91	0.94	0.93	0.95
SEC, SEP	1.06	0.68	1.04	0.61	0.84	0.46	0.41	0.37
SD	3.04	2.93	3.21	2.94	2.49	2.13	2.03	2.01
RPD	2.86	4.31	3.09	4.82	2.96	4.63	4.95	5.43
Range	9.99	7.3	9.32	8.04	8.57	5.72	6.14	5.04
RER	9.42	10.73	8.96	13.18	10.2	12.43	14.97	13.62

r: correlation coefficient, SEC:Standard Error of Calibration, SD:Standard Deviation, RPD:Ratio Prediction to Deviation, RER:Range to Error Ratio, Ref: Reflectance, Abs: Absorbance.

Maturity at harvest is an important factor affecting quality perception and the rate of change of quality during postharvest handling (Shewfelt 2009). Thus, it is critical to obtain measures of maturity. Maturity estimation by measuring the size, weight, density or using physical attributes such as color, firmness or morphological evaluation is often relying on the experience of trained labor. The estimation could be bias and different from one to another estimator. The change of composition of soluble solid content in different maturity stages was accurately estimated by NIRS. Absorbance spectra showed a higher coefficient correlation than reflectance spectra for soluble solid content and firmness. Reflectance spectra is lesser accurate because it is affected by size and shape of the sample particles . Absorbance spectra has weak intensity but yielding broad band spectra arise from functional groups of food and useful for quantitative analysis (Wehling 2003).

The estimation of firmness was fair, though not better than soluble solid content. This is in accordance with the literature that the accuracy of calibration models for firmness is usually worse than for soluble solid content (Penchaiya *et al*. 2009). Firmness is a physical parameter that is measured indirectly by NIRS through the change of pectin, while soluble solid content is a chemical parameter measured by NIRS through OH bound of the molecule.

Conclusions

From this study, it can be concluded that NIR can be used to develop prediction models for internal quality of mature mangoes such as total soluble solids and firmness. The quality of the model performance was cultivar specific with special emphasis on the different maturity indices. These findings can be utilized by the mango plantation to improve the efficiency during harvesting and in the developing a grading system that is based on the rapid prediction of quality parameter of the fruit.

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