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Jurnal Keteknikan Pertanian, Departemen Teknik Pertanian, Fakultas Teknologi Pertanian,
Kampus IPB Darmaga, Bogor 16680. Telp. 0251-8624691, Fax 0251-8623026,
E-mail: jtep@ipb.ac.id atau jurnaltep@yahoo.com. Website: ipb.ac.id/~jtep.

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Technical Paper

Non Destructive Inner Quality Prediction In Intact Mango With Near Infrared Reflectance Spectroscopy

Pendugaan Mutu Dalam Buah Mangga Menggunakan Spektroskopi Reflektan Infra Merah Dekat

Agus A Munawar[1] dan I Wayan Budiastra[2]

Abstract

Two major parameters which determine inner quality and the taste of mango, total soluble solids (TSS) and firmness, are still determined destructively. To evaluate the feasibility of near infrared reflectance spectroscopy (NIRS) technique in determining total soluble solids (TSS) contents and firmness in intact mango, diffuse reflectance (R) spectra were measured in the spectral range from 900 to 1400 nm. Calibration models using R and log (1/R) were established by stepwise multiple linear regression with k-fold leave one out (LOO) cross validation. The correlation coefficients (r) of calibrations ranged from 0.89 to 0.96 with SEC values 0.46 to 1.08. Both TSS and firmness were predicted accurately using log (1/R) spectra.

Keywords: *mango, NIRS, firmness, TSS, non-destructive*

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Introduction

Mango is one of the most important fruits in tropical horticultural products and a popular fruit for people around the world due to its taste, appearance and excellent overall nutritional source. In general, consumers purchase fresh fruits and vegetables on the basis of quality. Two major parameters determine inner quality and the taste of mangoes. These are total soluble solids (TSS) and firmness, which are still determined destructively. Paz *et al.* (2008) report that TSS increases with ripening but that the use of TSS alone as a ripeness index is limited variation among varieties, production area and season. Nevertheless, Crisoto (1994) suggests that TSS can be considered as a good quality index. On the other hand, firmness is a key parameter in mango, since it is directly related to fruit ripeness, and is often a good indicator of shelf life (De Ketelaere *et al.*, 2006; Valero *et al.*, 2007). Fruit firmness has major economic implications, soft fruits being more susceptible to bruising (Crisoto *et al.*, 2004).

The Near Infrared Reflectance Spectroscopy (NIRS) has been widely used to non-destructively measure inner quality in a wide range of fruits and vegetables, such as plum fruit (Onda *et al*., 1995), orange (Kawano *et al*., 1998), kiwifruit (McGlone and Kawano, 1998), maize (Brenna and Berado, 2004), carrots (Abu Khalaf *et al*., 2004), cherries fruit (Lu, 2001), apples (Lammertyn *et al*., 1998; Peirs *et al*., 2002), peaches (Kawano *et al*., 1992; Slaughter, 1998; Ying *et al*., 2005), tomato (He *et al*., 2005). NIRS is a non-destructive technique for analysing ingredients and inner quality in foods and agricultural products. It has been successfully implemented throughout the food industry, since it allows short measuring times without sample preparation, offering the advantage that more than one quality parameter can be estimated at the same time (Lammertyn *et al*., 1998). Therefore, the objective of this study was to evaluate the feasibility of NIRS for measuring firmness and TSS in intact *Arumanis* mango.

Materials and Methods

Spectra Measurement

Diffuse reflectance in the 900 to 1400 nm region were measured and recorded for 297 mangoes using Shimadzu NIRS unit. The NIRS unit (fig.1) consisted a wide band light source (100 W halogen lamp), chopper, monochromator and fruit holder. The light from the halogen lamp was guided to the sample by source fiber and from the sample with the detector fibers to near infrared spectrometer, with spectral range of 900-1400 nm. The chopper was used as a light cut off with its frequency is 50 Hz. The photodiode sensor was used to capture the light reaction given by the fruit and it was gained at the amplifier. An analog to digital converter (ADC) interface was used to convert voltage resulted as

[1] Staf Pengajar Jurusan Teknik Pertanian, Fakultas Pertanian Universitas Syiahkuala Banda Aceh
[2] Staf Pengajar Departemen Teknik Pertanian, Fakultas Teknologi Pertanian, Institut Pertanian Bogor. Email: wbudiastra@yahoo.com

reflectance spectra. Thus, the reaction from the sample mango was recorded and displayed as a spectra signature at the computer display.

TSS and Firmness Measurement

Total soluble solids and firmness were determined with traditional destructive tests. TSS (in ^{o}Brix) was measured using digital hand-refractometer model N1 Atago. The higher ^{o}Brix values, the more TSS contents in mango fruits. Meanwhile, fruit firmness was measured using rheometer model CR100. These two parameters measurement were performed after spectra measurement.

Data Analysis and Processing

Near infrared reflectance spectra data of mango were processed to develop calibration models. Data acquisition and spectra storage were achieved with personal computer (PC) running specially developed software Borland C++. It was the first step of data processing in this experiment where all the near infrared reflectance spectra were controlled. Once these preprocessing procedures were completed, the reflectance spectra were transformed into absorbance spectra via log (1/R), where R indicates the reflectance spectra for each mango. *Stepwise* method from multiple linear regressions was used to select the optimum wavelength and develop calibration models using both reflectance and absorbance spectra for predicting total soluble solids and firmness parameters in mango.

According to Osborne *et al.* (1993), calibration is the process of creating a spectro-chemical prediction models. In essence, the process relates chemical information contained in the spectral properties of mango to chemical or physical information revealed by reference standard laboratory methods. The calibration models quality developed using reflectance data were compared with the absorbance ones by looking their standard error calibration and coefficient of correlation value to decide which spectra data were to be used for cross validation. The good calibration models should have high correlation coefficient value and low value of standard error calibration.

Once these selection processing was complete, the K-fold leave one out cross validation (LOOCV) was performed to test the selected spectra data. As the name suggests, the leave one out cross validation involves using a single observation from the original sample as the validation data, and the remaining observations as the training data. This is repeated such that each observation in the sample is used once as the validation data. The total amount of 260 mango was divided into three groups, whereas group 1 and group 2 contains a hundred mangoes respectively and the remaining samples, 60 mangoes was named as group 3. Each mango which belongs to a group was selected randomly. To judge the cross validation performance, the standard error for cross validation (SECV) and the ratio between the standard deviation in calibration and standard error for cross validation (RPD) were then calculated. Moreover, the calibration models were then tested using the remaining 37 independent samples. Beside the coefficient of correlation (r) and RPD, the standard error for prediction (SEP) corrected by bias and the ratio between the range and SEP or called RER were also calculated to quantify the prediction performance.

Results and Discussion

The near infrared spectra of mango can be derived as an absorbance and reflectance pattern

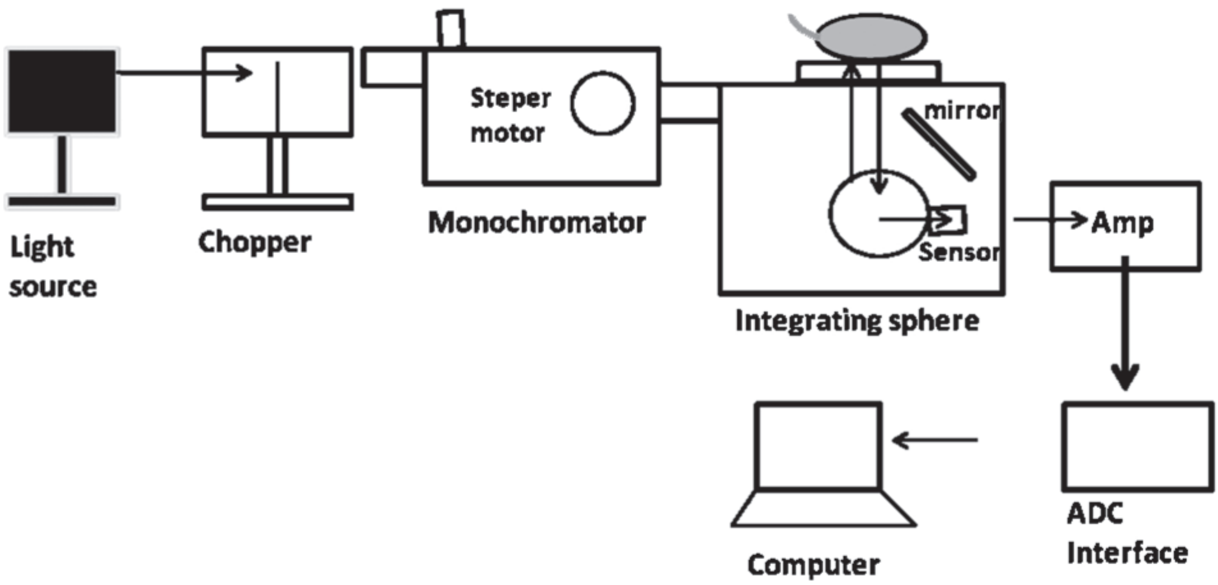

Figure 1. The NIRS unit measurement (Budiastra *et al.*, 1992

where this pattern contains important information describing the chemical and physical properties of mango as a consequence of electro-magnetic radiation. These radiation consists of photons of different energies and because of these differences, the reactions of all organic matter were also in very different ways and thus lead to some special information and characteristics of objects. The reflectance and absorbance spectra of typical *Arumanis* variety measured in intact fruits are shown below where the graph is plotted as reflectance or log (1/R) versus near infrared wavelength.

It was clearly found that water may absorb more light in the near infrared region starting at around 1310 nm where the absorbance spectra signature was increased continously. Similar findings are reported by Wilkie and Finn (1996) who note that the wavelength in near infrared region of 1300 nm and above were the water absorbance wavelength. Meanwhile, the specific information about fruit chemical composition and physical properties was found from the wavelength of 920 to 1275 nm, since in this wavelength region, the fruit tissue were played the role of spectra trend signatures.

The aim of creating calibration was to derive a predictive equation such that the user can quantify the constituent of interest, where in this experiment it was used to predict the total soluble solids composition and firmness of *Arumanis* mango using the near infrared spectroscopy unit alone, bypassing the laboratory reference method. Based on statistical evaluation for SEC and r performance,

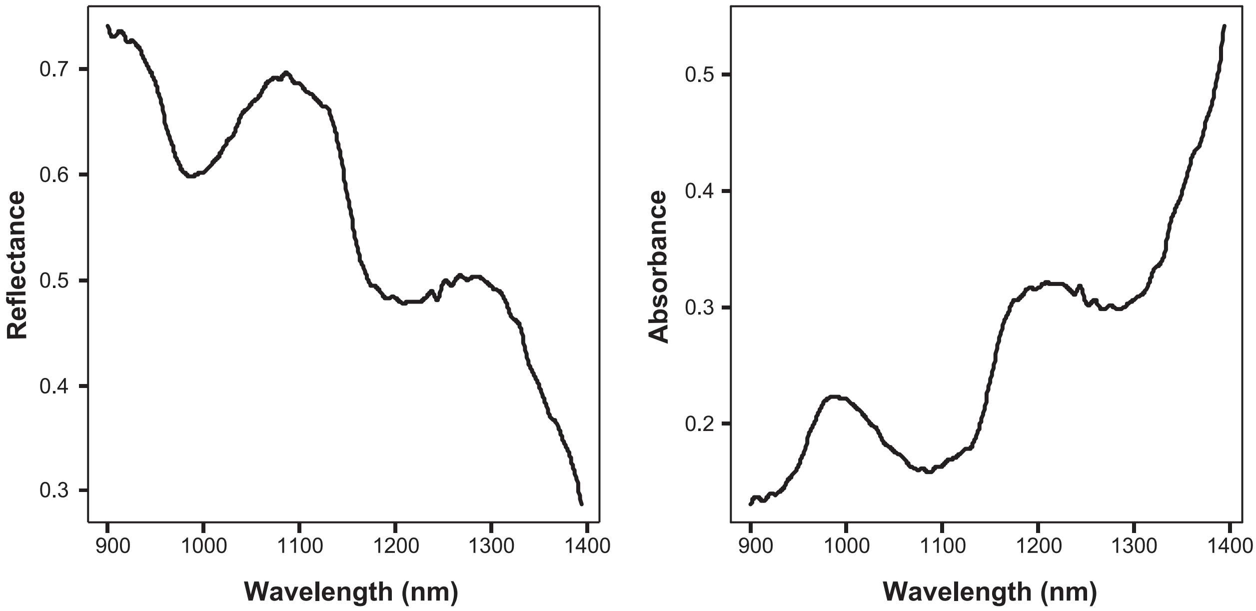

Figure 2. Typical reflectance and absorbance spectra for one intact *Arumanis* mango in near infrared region 900-1400 nm

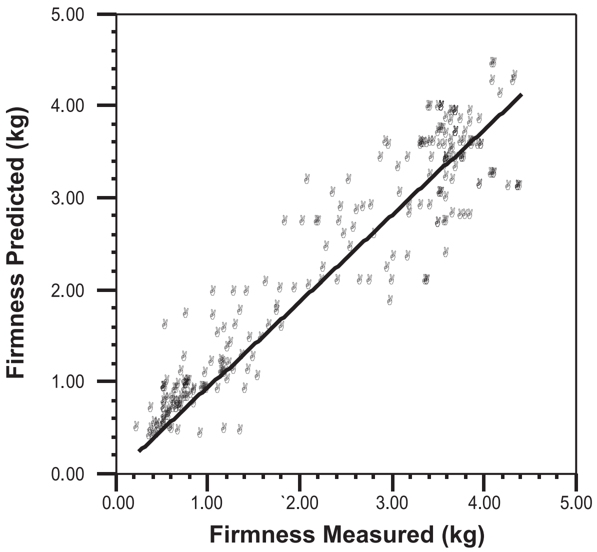

Figure 3a. Calibration results for firmness prediction with absorbance spectra *(r= 0.94 and SEC= 0.46)*

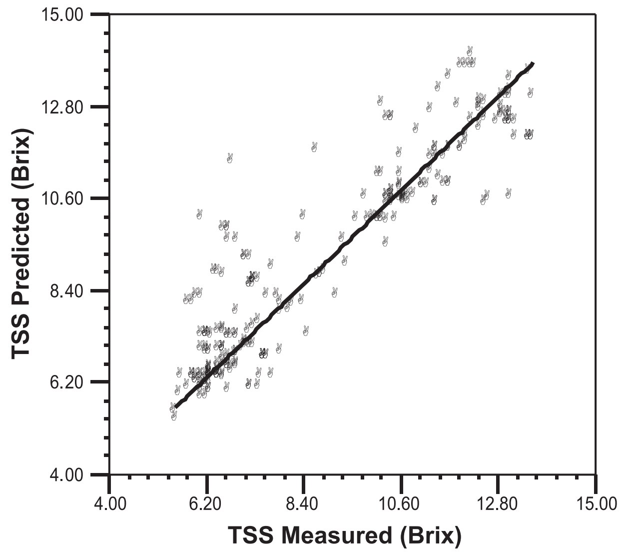

Figure 3b. Calibration results for TSS prediction with absorbance spectra *(r=0.96 and SEC=0.71 ^{O}Brix)*

Table 1. Statistical evaluation result for firmness and TSS calibration model

Statistical parameter	Firmness		TSS	
	Reflectance	Absorbance	Reflectance	Absorbance
r	0.89	0.94	0.91	0.96
SEC	0.64	0.46	1.08	0.71

Table 2. Cross validation results using log(1/R) spectra

Statistical parameter	TSS	Firmness
r	0.95	0.93
SECV	0.73	0.48
SD	2.49	1.24
RPD	3.61	2.69

Table 3. Prediction results using log(1/R) spectra

Statistical parameters	Total soluble solids	Firmness
n	37	37
r	0.95	0.89
bias	0.17	0.02
SEP	1.04	0.05
SD	2.93	0.13
RPD	2.82	2.60
RER	9.60	10.20
min	11.10	0.29
max	21.10	0.80
range	9.99	0.51
mean	16.80	0.54

calibration using absorbance spectra were given better results in predicting TSS and firmness in intact mango. One possibly reasons, according to literature (Lammertyn *et al*., 1998, Tsenkova *et al*.,1999 and Mahayothee *et al*.,2002) the optical disturbance and errors were reduced when the near infrared reflectance spectra were transformed into absorbance data. The *stepwise* regression chose seven optimum wavelengths for TSS prediction and chose six optimum wavelengths for firmness prediction.

The exact wavelength of 910 was to be believed is one of the most responsible absorption bands for predicting soluble solids contents. Lammertyn *et al.* (2000) reported that sugars group in aqueous solution has absorption bands at 838, 888, 910 and 913 nm. Moreover, Slaughter (1998) reported that even absorbance spectra gave clear results in predicting total soluble solids, there is no sufficient character to use these spectra to distinguish individual sugars from another. However, post-processing these spectra into its second derivatives treatment enhances the calibration model performance.

Cross validation using absorbance spectra indicated that seven factors multiple linear regression model for total soluble solids and six factors for firmness model was appropriate for predicting both maturity parameters, providing coefficient of correlation of 0.95 and 0.93 with standard error calibration of 0.73 ^{o}Brix and 0.48 kg respectively. These cross validation results are shown in Table 2.

When calibration models were tested using the remaining 37 independent samples, it also gave a good result providing coefficient of correlation of 0.95 for total soluble solids prediction with standard error prediction of 1.04 ^{o}Brix and coefficient of correlation of 0.89 for firmness with standard error prediction of 0.05 kg.

Based on table above, it may conclude that the advantages of NIRS as a non-destructive method become evidence. Furthermore, William (2001) stated that calibration models with RPD around 3 or higher and RER of 9 or higher indicated an efficient and *‘fair’* enough of near infrared reflectance calibration model for agricultural products.

Conclusions

The research indicated that it is possible to develop a non-destructive technique for measuring total soluble solids (TSS) in intact mango as well as the firmness of intact mango by NIRS. The results seemed good with r=0.95 and 0.89, SEP=1.04 and 0.05, RER=9.60 and 10.20 for TSS and firmness prediction respectively.

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