

Quality Prediction of Kiwifruit Based on Near Infrared Spectroscopy

Jin Su Lee¹, Seong-Cheol Kim^{1*}, Ki Cheol Seong¹, Chun-Hwan Kim¹,
Yeong Cheol Um², and Seung-Koo Lee³

¹National Agricultural Research Center for Climate Change, National Institute of Horticultural & Herbal Science, Rural Development Administration, Jeju 690-150, Korea

²Vegetable Research Division, National Institute of Horticultural & Herbal Science, Suwon 440-706, Korea

³Department of Plant Science, Seoul National University, Seoul 151-921, Korea

Abstract. To establish the standard of ripe kiwifruit sorting, near infrared (NIR) spectroscopy was performed on kiwifruit sampled from three farms. Destructive measurements of flesh firmness, soluble solids content (SSC), and acidity were performed and compared to measurement using NIR reflectance spectrums from 408 to 2,492 nm. NIR predictions of those quality factors were calculated using the modified partial least square regression method. Flesh firmness was predicted with a standard error of prediction (SEP) of 3.32 N and with a correlation coefficient (R^2) of 0.88. SSC was predicted with SEP of 0.49 °Brix and with R^2 of 0.98. Acidity was predicted with SEP of 0.28% and with R^2 of 0.91. Kiwifruit ripened at 20°C for 15 days showed uneven qualities with normal distribution. Considering the SEP of each parameter, kiwifruit after ripening treatment could be non-destructively predicted their qualities and sorted by flesh firmness or soluble solids content through NIR prediction.

Additional key words: acidity, *Actinidia deliciosa*, non-destructive, soluble solids content, sorting

Introduction

Kiwifruit [*Actinidia deliciosa* (A. Chev.) Liang et Ferguson, cv. Hayward] become edible level when they are ripened after harvest like avocado, banana, and mango. During ripening there are three major changes in kiwifruit; decrease of flesh firmness and acidity, and conversion of starch to sugar. These three factors are important in quality evaluation. However, every kiwifruit does not reach uniform level of quality after ripening. The variations of quality factors are explained by different patterns of sugar and starch formation inside fruit grown under different conditions (MacRae et al., 1989). Therefore, measuring the quality non-destructively and sorting into different grades before packing and shipping products are very important in kiwifruit from the marketing point of view.

There were many previous studies of non-destructive methods such as magnetic resonance imaging, X-ray computer tomography, non-contact laser air-puff method, and acoustic impulse-response technique (Lammertyn et al., 2003; McGlone and Jordan, 2000; Schotte et al., 1999). However, near infrared

(NIR) spectroscopy is the most prevalent among those non-destructive methods, because NIR spectroscopy is easy to handle, low in cost and high in accuracy (Clark et al., 2003; Osborne et al., 1999).

NIR spectroscopy has been studied for measuring internal properties such as soluble solids content (SSC), pH, dry matter, flesh color, and flesh firmness to evaluate the possibility of estimating kiwifruit quality (Martinsen and Schaare, 1998; McGlone and Kawano, 1998; McGlone et al., 2002; Moghimi et al., 2010; Schaare and Fraser, 2000; Schotsmans et al., 2007). However, there was no attempt to apply NIR spectroscopy estimating equation to sorting kiwifruit practically.

In this study, NIR spectroscopy was performed to predict the quality such as flesh firmness, SSC, and acidity of kiwifruit non-destructively.

Materials and Methods

Fruit Material

Kiwifruit [*Actinidia deliciosa* (A. Chev.) Liang et Ferguson,

*Corresponding author: kimsec@korea.kr

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cv. Hayward] were harvested from three farms (designated as F-1, F-2, and F-3) in November and stored in a storage room in which temperature was set at 2°C. Fruit ripening was performed at 20°C.

NIR Method

NIR spectra of intact fruit were measured with a NIR spectrophotometer (NIRSystem 6500, Silver Spring, MD, USA). The spectrophotometer scanned absorbance at 2 nm sampling wavelength intervals and a speed of 1.8 scans per sec. A spectral range covered the entire visible (408-700 nm), very NIR (700-1,092 nm), and NIR (1,108-2,492 nm). A ceramic cell was used to provide a reference spectrum before achieving absorbance spectra of each sample (McGlone and Kawano, 1998). Prior to NIR measurement all the samples were controlled to 20°C, since the sample temperature influences the performance of a NIR calibration equation (Kawano et al., 1995; Peinado, 2006).

Development of NIR Prediction Regression

Each fruit from three farms was ripened at 20°C on the day of harvest to establish NIR calibration curve for a wide range of flesh firmness, SSC, and acidity. From the next day, 90 fruits obtained from each farm were assessed for a single NIR spectrum every five days for 25 days. Totally 450 fruits from each farm were used for the calibration set. Additional twelve fruits obtained from each farm were accessed for validation set every five days for 25 days. Total 60 fruits from each farm were used for the validation set. Statistical

characteristics of calibration and validation sets were shown in Table 1.

The best calibration method of F-1 was selected by treating the factors influencing calibration such as wavelength range, interval, and math treatment. Then the selected method was applied to F-2, F-3, and F-all (combined samples from all farms). Absorbance of F-1 set was measured in the region of 408-2,494, 700-1,092, 1,108-2,492, 408-1,092, and 700-2,494 nm to select the best wavelength region of NIR spectra calibration. Wavelength intervals of 4 nm were compared with 8 nm for the accuracy of calibration, since wavelength interval also influences the accuracy of calibration by determining a number of wavelength. Pretreating spectra and developing calibration equation method were the modified following procedures described by Saranwong et al. (2004) and Park et al. (2004). Spectra pretreatments of principle component analysis, standard normal variate and detrend, and first or second derivative (segment = 4 nm, gap = 4 nm) were performed as a data pretreatment to obtain the best calibration result. In the math treatment, first derivative was compared with second derivative to get the most accurate calibration. Modified partial least square was used to develop calibration equations. The calibration equations were applied to spectra in the validation set. The statistics standard error of calibration (SEC), standard error of prediction (SEP), and bias between predicted and actual data were calculated to judge accuracy of the model. WinISI II Project Manager 1.50 (Foss NIRSystem, USA) was used for pretreating the spectra, developing calibration equation, and calculating validation.

Table 1. Statistical characteristics of calibration and validation sets of kiwifruits obtained from different farms.

Farm	Calibration set			Validation set		
	Range	Mean	SD ^z	Range	Mean	SD
Flesh firmness (N)						
F-1	5.10-41.16	25.13	11.61	5.68-39.69	22.44	11.14
F-2	7.84-34.30	20.32	6.84	9.31-32.83	21.59	6.65
F-3	7.35-41.16	23.37	9.17	8.13-39.69	24.69	9.88
F-all ^y	5.10-41.16	22.95	9.61	5.68-39.69	22.77	9.43
SSC (°Brix)						
F-1	5.30-17.60	10.66	3.70	5.80-16.40	11.89	3.23
F-2	6.20-16.80	12.92	2.83	6.20-16.10	11.40	3.03
F-3	5.40-16.80	12.37	3.09	5.90-16.40	11.78	3.08
F-all	5.30-17.60	11.98	3.36	5.80-16.40	11.69	3.11
Acidity (%)						
F-1	0.41-3.77	2.09	1.06	0.59-3.58	2.00	0.99
F-2	0.43-3.24	1.63	0.74	0.56-3.24	1.70	0.81
F-3	0.40-3.73	1.58	0.76	0.54-3.48	2.04	0.93
F-all	0.40-3.77	1.77	0.89	0.54-3.58	0.91	0.92

^zStandard deviation.

^yCombined data set from all farm.

450 fruits from each farm were used for the calibration set. 60 fruits were used for validation.

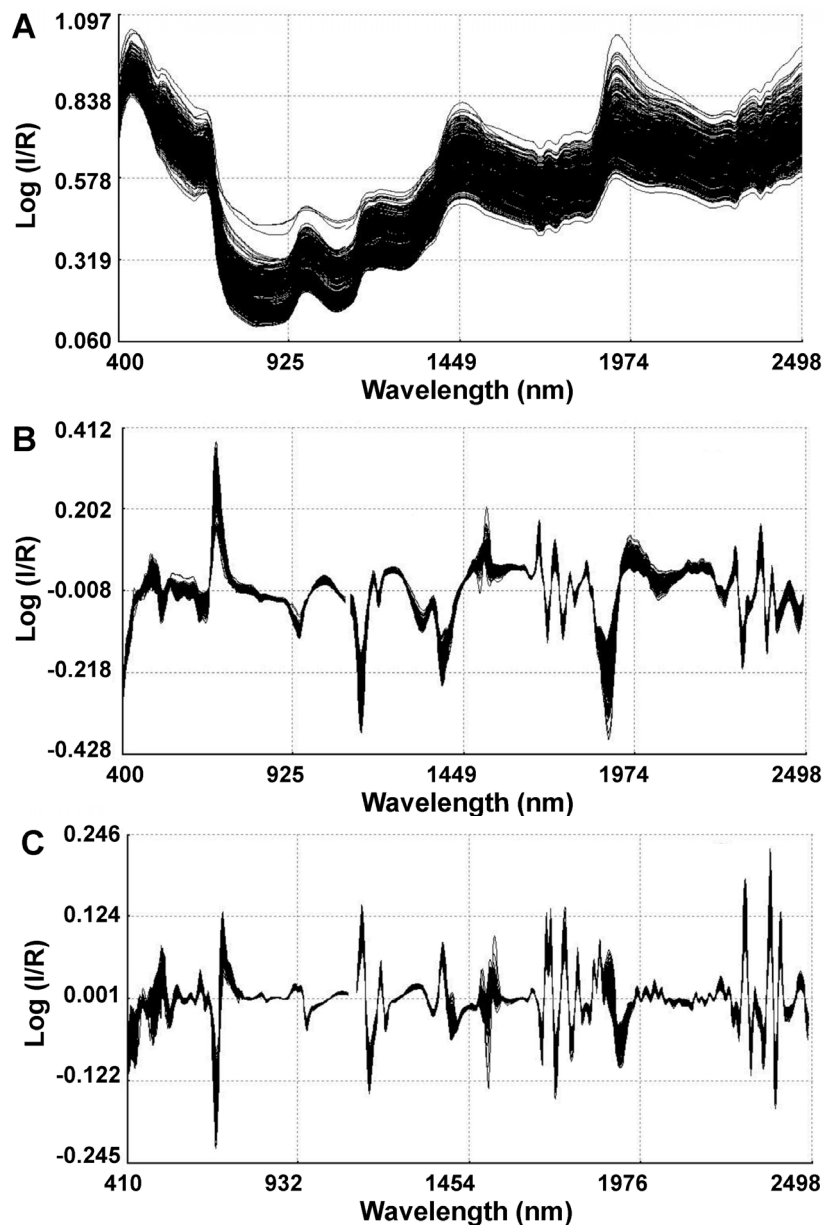


Fig. 1. Original absorbance (A), first derivative (B) and second derivative spectra (C) of kiwifruits.

Measurement of Flesh Firmness, SSC, and Acidity

A slice of skin was removed from each fruit prior to measuring flesh firmness. Flesh firmness was measured using a hand-held penetrometer (FHR-5, Takemura, Japan) with a 5 mm probe. Flesh firmness was then calculated in Newton. SSC and acidity were measured using an auto SSC and acidity analyzer (NH-2000, Horiba, Japan) that requires 5 mL of juice to get a reliable reading. SSC and acidity were expressed as °Brix and %, respectively.

Results and Discussion

Spectral Characteristics of Kiwifruit

Original and first derivative absorbance spectra ranged

400-2,500 nm of kiwifruit (F-1 set) in various quality characteristics were shown in Fig. 1. With original spectra, it was very difficult to find any relationship among spectral characteristics and actual quality factors. Math treatment was used in the analysis of NIR absorbance spectra. First and second derivation of original spectra minimized the factors that changed base line of absorbance and interrupt absorbance such as sample temperature, density, and constructive variation (Park et al., 2004).

NIR Prediction of Flesh Firmness, SSC, and Acidity

The accuracy of calibration was evaluated by SEC, R^2 , SEP, and multiple correlation coefficients of validation (R_v^2). A calibration equation in high accuracy was low in SEC

Table 2. Calibration and validation statistics for predicting flesh firmness of kiwifruits.

Wavelength (nm)	Interval (nm)	Math treatment ^z	Calibration		Validation	
			SEC ^y (N)	R ²	SEP ^x (N)	R _v ^{2w}
408-2,492	4	1, 4, 4, 1	2.39	0.94	2.99	0.93
		2, 4, 4, 1	2.04	0.95	2.80	0.94
	8	1, 4, 4, 1	2.33	0.85	2.93	0.93
		2, 4, 4, 1	2.11	0.94	3.00	0.93
700-1,092	4	1, 4, 4, 1	2.58	0.95	4.23	0.87
		2, 4, 4, 1	2.67	0.95	4.40	0.86
	8	1, 4, 4, 1	2.61	0.95	4.21	0.87
		2, 4, 4, 1	2.68	0.95	4.36	0.87
1,108-2,492	4	1, 4, 4, 1	2.06	0.97	2.96	0.93
		2, 4, 4, 1	2.34	0.96	3.85	0.88
	8	1, 4, 4, 1	2.14	0.97	2.94	0.93
		2, 4, 4, 1	2.42	0.96	4.05	0.87
408-1,092	4	1, 4, 4, 1	2.34	0.95	4.53	0.86
		2, 4, 4, 1	2.25	0.95	4.45	0.86
	8	1, 4, 4, 1	2.36	0.95	4.46	0.86
		2, 4, 4, 1	2.21	0.95	4.45	0.87
700-2,492	4	1, 4, 4, 1	2.32	0.96	3.06	0.92
		2, 4, 4, 1	2.31	0.96	3.34	0.91
	8	1, 4, 4, 1	2.32	0.96	2.95	0.93
		2, 4, 4, 1	2.32	0.96	3.44	0.91

^z1, 4, 4, 1 = first derivative, 2, 4, 4, 1 = second derivative.

^yStandard error of calibration.

^xStandard error of prediction.

^wMultiple correlation coefficient of validation.

450 fruits from F-1 farm were used for calibration.

60 fruits were used for validation.

Table 3. Calibration and validation statistics for NIR prediction modeling of flesh of kiwifruits obtained from different farms.

Farm	Calibration		Validation		
	SEC ^z (N)	R ²	SEP ^y (N)	R _v ^{2x}	Bias ^w (N)
F-1	2.04	0.95	2.80	0.94	0.020
F-2	2.11	0.87	3.05	0.80	0.784
F-3	2.34	0.90	3.21	0.90	0.010
F-all	2.98	0.88	3.32	0.88	0.697

^zStandard error of calibration.

^yStandard error of prediction.

^xMultiple correlation coefficient of validation.

^wThe average of difference between actual value and NIR value.

450 fruits from each farm were used for calibration.

60 fruits from each farm were used for validation.

and SEP, but high in R² and R_v² (Adesogan et al., 1998). Flesh firmness prediction of F-1 was most accurate in the range of 408-2,492 nm at the interval of 4 nm and in the math treatment of second derivative (Table 2). When the selected wavelength and math treatment factors were applied to F-all, calibration and validation statistics of flesh firmness were SEC = 2.98 N, R² = 0.88, SEP = 3.32 N, and R_v² = 0.88 (Table 3 and Fig. 2). In the previous studies of flesh

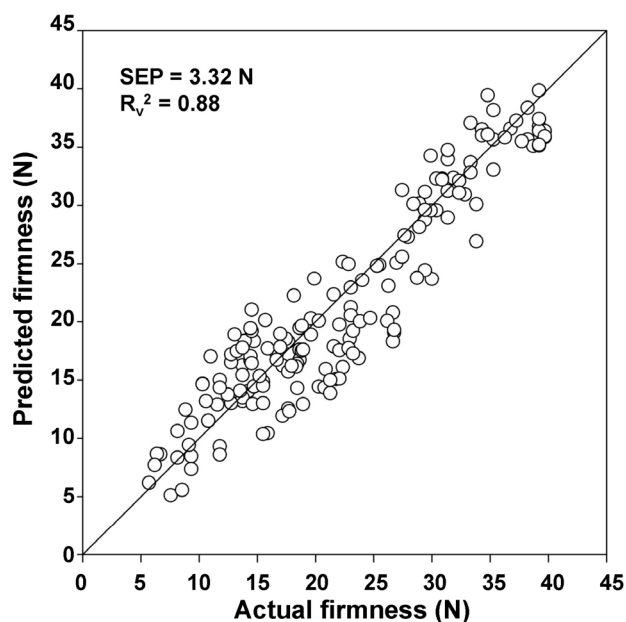


Fig. 2. Relation between actual and predicted flesh firmness of kiwifruits from F-all. Regression statistics (n = 180) was displayed. Fruits in different ripening stage were used for validation by sampling every five days for 25 days during ripening. SEP = standard error of prediction and R_v² = multiple correlation coefficient of validation.

firmness prediction of kiwifruit, wavelengths did not exceed 1,200 nm and predictions were relatively low in accuracy to this study. McGlone and Kawano (1998) and Costa et al. (1999) predicted flesh firmness with SEP of 7.8 N using 800-1,100 nm and with SEP of 0.61 kg·cm⁻² using 650-1,200 nm, respectively. Similarly, calibration with very NIR region not included above 1,108 nm in this study resulted in poor calibration compared to other wavelength regions. However, in this study, the accuracy of flesh firmness prediction was improved by including wavelength region of 1,108-2,492 nm. This result was supported by the report of Sohn and Cho (2000), who predicted flesh firmness of apple by measuring pectin using 1,100-2,500 nm. In the experiment of applying prediction model of specific farm to the other farms, the flesh firmness model of F-1 and F-2 did not predict flesh firmness of F-3 well compared to F-all (Table 4). Since internal characteristics of the fruits were different among farms by different circumstances of cultivation, in order to predict fruit quality with accuracy, the best way is to develop prediction model of various farms.

SSC prediction of F-1 was most accurate in the range of 408-2,492 nm at the interval of 8 nm and in the math

treatment of second derivative (Table 5). Using the wavelength 700-2,492 nm at the interval of 8 nm and the math treatment of second derivative, SEC was 0.32 °Brix which was the lowest. However, it was not selected since the SEP was higher than 0.48 °Brix. Exclusion of wavelengths above 1,108 nm resulted in poor calibration compared to the other wavelength regions. When the selected wavelength and math treatment factors were applied to F-all, calibration and validation statistics of SSC were SEC = 0.45 °Brix, R² = 0.98, SEP

Table 4. Regression statistics for flesh firmness prediction between different farms using calibration sets (row labels) and validation set (column labels).

Calibration set	Validation set (F-3)		
	SEP ^z (N)	R _v ^{2y}	Bias ^x (N)
F-1	6.84	0.54	-0.118
F-2	6.09	0.74	2.871
F-all	3.76	0.86	0.931

^zStandard error of prediction.

^yMultiple correlation coefficient of validation.

^xThe average of difference between actual value and NIR value. 60 fruits were used for validation set.

Table 5. Calibration and validation statistics for predicting SSC of kiwifruits.

Wavelength (nm)	Interval (nm)	Math treatment ^z	Calibration		Validation	
			SEC ^y (°Brix)	R ²	SEP ^x (°Brix)	R _v ^{2w}
408-2,492	4	1, 4, 4, 1	0.38	0.99	0.49	0.98
		2, 4, 4, 1	0.33	0.99	0.53	0.97
	8	1, 4, 4, 1	0.38	0.99	0.51	0.98
		2, 4, 4, 1	0.33	0.98	0.48	0.98
700-1,092	4	1, 4, 4, 1	0.60	0.97	0.64	0.96
		2, 4, 4, 1	0.58	0.98	0.64	0.96
	8	1, 4, 4, 1	0.62	0.97	0.65	0.96
		2, 4, 4, 1	0.64	0.97	0.70	0.95
1,108-2,492	4	1, 4, 4, 1	0.41	0.99	0.64	0.96
		2, 4, 4, 1	0.39	0.99	0.73	0.95
	8	1, 4, 4, 1	0.43	0.99	0.69	0.96
		2, 4, 4, 1	0.40	0.99	0.69	0.96
408-1,092	4	1, 4, 4, 1	0.55	0.97	0.78	0.95
		2, 4, 4, 1	0.58	0.97	0.72	0.95
	8	1, 4, 4, 1	0.59	0.97	0.76	0.95
		2, 4, 4, 1	0.58	0.97	0.78	0.94
700-2,492	4	1, 4, 4, 1	0.38	0.99	0.49	0.98
		2, 4, 4, 1	0.35	0.99	0.51	0.98
	8	1, 4, 4, 1	0.39	0.99	0.51	0.98
		2, 4, 4, 1	0.32	0.99	0.51	0.98

^z1, 4, 4, 1 = first derivative, 2, 4, 4, 1 = second derivative.

^yStandard error of calibration.

^xStandard error of prediction.

^wMultiple correlation coefficient of validation.

450 fruits from F-1 farm were used for calibration.

60 fruits were used for validation.

= 0.49 °Brix, and $R_v^2 = 0.98$ (Table 6 and Fig. 3). The SEP of SSC was significantly low compared to other published kiwifruit data; 1.2 °Brix (Martinsen and Schaare, 1998) and 1.18 °Brix (Schaare and Fraser, 2000). They predicted kiwifruit covered from unripe to overripe stage similar to the ripening stage of F-all set. However, the predictions were not as accurate as F-all set, since the measured absorbance in NIR region is below 1,100 nm. By comparing wavelength, the accuracy of SSC prediction was improved by including wavelength region of 1,108-2,492 nm. Some previous papers reported lower prediction error of SSC in kiwifruit; root mean square error of prediction (RMSEP) = 0.39 °Brix (McGlone and

Kawano, 1998), and root mean square error of cross validation = 0.27 °Brix (Osborne et al., 1999). However those results could not be compare to SSC prediction of F-all, since they predicted ripe kiwifruit ranged from 10 to 16 °Brix with interactance method. Generally interactance method is more accurate than reflectance, since it is not susceptible to specular reflection which hinders accurate measurement (Martinsen and Schaare, 1998; Schaare and Fraser, 2000). However, accuracy of prediction using the interactance method was decreased when measuring wide ranged SSC of kiwifruit at different ripening stages, referring to the result of Clark et al. (2004) who predicted ripe kiwifruit ranged from 5 to 19 °Brix with interactance NIR method with an SEP of 0.92 °Brix. Recently, Moghimi et al. (2010) reported improved SSC prediction model with transmission method exhibiting RMSEP = 0.259 °Brix. However this improvement needs to be considered that transmission method is also more accurate than reflectance method (Schaare and Fraser, 2000) and they used less fruit (70 fruit for calibration and 30 fruit for validation) and narrow range of SSC of the target fruit (12 to 14.5 °Brix). Considering all previous reports, SSC prediction of F-all can be acceptable. Similar to flesh firmness prediction, F-1 and F-2 calibration did not predict well F-3 compared to F-all calibration did; SEP = 0.68, 1.49, and 0.54 °Brix, respectively (Table 7).

Acidity prediction of F-1 was most accurate in the range of 408-2,492 nm at the interval of 8 nm and in the math treatment of first derivative (Table 8). Using the wavelength 700-2,492 nm at the interval of 8 nm and the math treatment of second derivative, SEC was 0.195% which was the lowest. However, it was not selected since the SEP was higher than 0.223%. Like the results of other quality factors, exclusion of wavelengths above 1,108 nm resulted in poor calibration compared to the other wavelength regions. When the selected wavelength and math treatment factors were applied to F-all, calibration and validation statistics of acidity were SEC = 0.26%, $R^2 = 0.91$, SEP = 0.28%, and $R_v^2 = 0.91$ (Table 9

Table 6. Calibration and validation statistics for NIR prediction modeling of SSC of kiwifruits obtained from different farms.

Farm line	Calibration		Validation		
	SEC ^z (°Brix)	R ²	SEP ^y (°Brix)	R _v ^{2x}	Bias ^w (°Brix)
F-1	0.33	0.98	0.48	0.98	0.036
F-2	0.35	0.97	0.44	0.98	0.024
F-3	0.35	0.98	0.50	0.97	0.047
F-all	0.45	0.98	0.49	0.98	-0.005

^zStandard error of calibration.

^yStandard error of prediction.

^xMultiple correlation coefficient of validation.

^wThe average of difference between actual value and NIR value. 450 fruits from each farm were used for calibration. 60 fruits were used for validation.

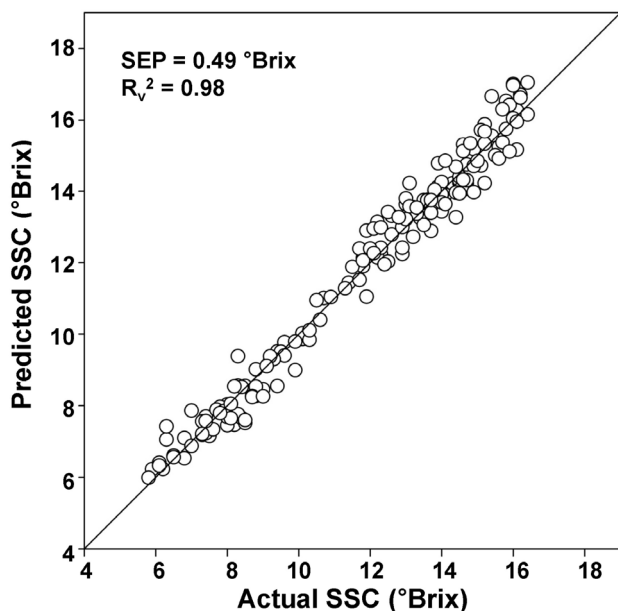


Fig. 3. Relation between actual and predicted SSC of kiwifruits from F-all. Regression statistics (n = 180) was displayed. Fruits in different ripening stage were used for validation by sampling every five days for 25 days during ripening. SEP = standard error of prediction and R_v^2 = multiple correlation coefficient of validation.

Table 7. Regression statistics for SSC prediction between different farms using calibration sets (row labels) and validation set (column label).

Calibration set	Validation set (F-3)		
	SEP ^z (°Brix)	R _v ^{2y}	Bias ^x (°Brix)
F-1	0.68	0.60	-0.355
F-2	1.49	0.94	-1.276
F-all	0.54	0.97	-0.002

^zStandard error of prediction.

^yMultiple correlation coefficient of validation.

^xThe average of difference between actual value and NIR value. 60 fruits were used for validation.

Table 8. The calibration and validation statistics for the prediction of acidity of kiwifruit.

Wavelength (nm)	Interval (nm)	Math treatment ^z	Calibration		Validation	
			SEC ^y (%)	R ²	SEP ^x (%)	R _v ^{2w}
408-2,492	4	1, 4, 4, 1	0.195	0.95	0.224	0.95
		2, 4, 4, 1	0.207	0.95	0.271	0.93
	8	1, 4, 4, 1	0.196	0.95	0.223	0.95
		2, 4, 4, 1	0.203	0.95	0.274	0.93
700-1,092	4	1, 4, 4, 1	0.325	0.91	0.357	0.88
		2, 4, 4, 1	0.333	0.90	0.387	0.86
	8	1, 4, 4, 1	0.334	0.90	0.358	0.88
		2, 4, 4, 1	0.329	0.91	0.371	0.87
1,108-2,492	4	1, 4, 4, 1	0.214	0.96	0.283	0.92
		2, 4, 4, 1	0.235	0.95	0.308	0.91
	8	1, 4, 4, 1	0.214	0.96	0.283	0.92
		2, 4, 4, 1	0.209	0.96	0.327	0.90
408-1,092	4	1, 4, 4, 1	0.282	0.91	0.387	0.85
		2, 4, 4, 1	0.265	0.92	0.381	0.86
	8	1, 4, 4, 1	0.301	0.90	0.362	0.87
		2, 4, 4, 1	0.270	0.92	0.385	0.86
700-2,492	4	1, 4, 4, 1	0.205	0.96	0.250	0.94
		2, 4, 4, 1	0.212	0.96	0.282	0.92
	8	1, 4, 4, 1	0.204	0.96	0.251	0.94
		2, 4, 4, 1	0.206	0.96	0.292	0.92

^z1, 4, 4, 1 = first derivative, 2, 4, 4, 1 = second derivative.

^yStandard error of calibration.

^xStandard error of prediction.

^wMultiple correlation coefficient of validation.

450 fruits from F-1 farm were used for calibration.

60 fruits were used for validation.

Table 9. Calibration and validation statistics for NIR prediction modeling of acidity of kiwifruits from different farms.

Farm line	Calibration		Validation		
	SEC ^z (%)	R ²	SEP ^y (%)	R _v ^{2x}	Bias ^w (%)
F-1	0.20	0.96	0.22	0.95	0.029
F-2	0.18	0.92	0.28	0.90	0.108
F-3	0.21	0.91	0.27	0.93	-0.062
F-all	0.26	0.91	0.28	0.91	0.005

^zStandard error of calibration.

^yStandard error of prediction.

^xMultiple correlation coefficient of validation.

^wThe average of difference between actual value and NIR value.

450 fruits from each farm were used for calibration.

60 fruits from each farm were used for validation.

and Fig. 4). NIR prediction of acidity was not performed with kiwifruit before. However, acidity of mango was predicted with SEP of 0.16 using 1,200-2,400 nm (Schmilovitch et al., 2000) and 0.20% using 650-2,500 nm (Mahayothee et al., 2002). The SEP was lower in mango than in kiwifruit, however the range of acidity was narrower in mango than in kiwifruit. Since the acidity of mango was narrower as

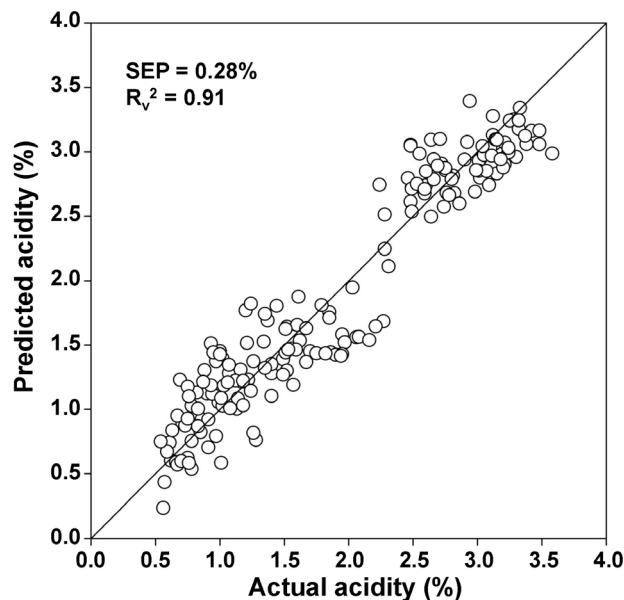


Fig. 4. Relation between actual and predicted acidity of kiwifruits from F-all. Regression statistics (n = 180) was displayed. Fruits in different ripening stage were used for validation by sampling every five days for 25 days during ripening. SEP = standard error of prediction and R_v² = multiple correlation coefficient of validation.

Table 10. Regression statistics for acidity prediction between different farms using calibration sets (row labels) and validation set (column label).

Calibration set	Validation set (F-3)		
	SEP ^z (%)	R _v ^{2y}	Bias ^x (%)
F-1	0.40	0.85	-0.095
F-2	0.57	0.80	-0.334
F-all	0.27	0.92	-0.063

^zStandard error of prediction.

^yMultiple correlation coefficient of validation.

^xThe average of difference between actual value and NIR value. 60 fruits from each farm were used for validation.

0.2-1.5% than that of kiwifruit as 0.4-3.8%, acidity prediction of kiwifruit was more acceptable than that of mango. F-1 and F-2 calibration did not predict well compared to F-all calibration did; SEP = 0.40, 0.57, and 0.27%, respectively (Table 10).

The wavelength regions determining absorbance of flesh firmness, SSC, and acidity were different each other. Therefore, the different wavelength and math treatment, and accuracy of prediction among quality factors such as flesh firmness, SSC, and acidity were used independently to develop prediction model of each quality index. The accuracy of quality prediction of kiwifruit was high or low according to the previous calibrated report. However, the prediction of kiwifruit quality using 408-2,492 nm can be applied for non-destructive sorting. In addition, different internal characteristics of fruit from different farms caused interruption to develop a universal estimation model by using fruit from single farm. Therefore, it is recommended that kiwifruits from diverse farms should be used to develop more accurate prediction model.

Application of NIR Prediction Equation to Sorting of Kiwifruit

Randomly selected 120 kiwifruit were ripened at 20°C for 15 days with variation. After ripening, normal distribution was observed in flesh firmness, SSC, and acidity of ripe kiwifruit (Fig. 5). Flesh firmness, SSC, and acidity ranged from 3 to 15 N, from 10.5 to 17.0 °Brix, and from 0.4 to 1.3%, respectively. Considering these variations of flesh firmness, SSC, and acidity, ripe kiwifruit could be divided into three groups such as less-ripe, ripe, and overripe by applying NIR spectroscopy quality estimation models. It is necessary for large packing houses to sort kiwifruit into several groups, since they deal considerable amount of shipment.

However, among the quality predictions, considering that SEP of acidity prediction was relatively high (0.28%) compared to the distribution of acidity after ripening treatment (0.4 to 1.3%), acidity prediction by NIR spectroscopy was not

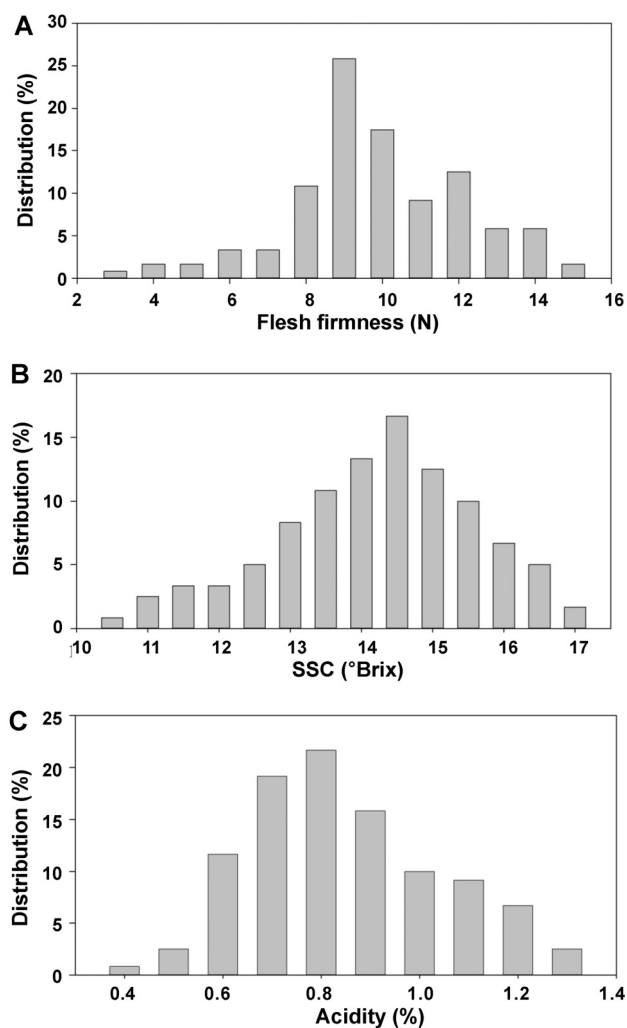


Fig. 5. Distribution of flesh firmness (A), SSC (B), and acidity (C) in 120 kiwifruit ripened at 20°C for 15 days.

accurate. Therefore using acidity estimation model is not recommended to the quality estimation index of ripe kiwifruit. However acidity prediction model may be applied as a screening tool to segregate fruit in low quality, since consumers felt sour when SSC was less than 11.6 °Brix and acidity was more than 1.17% in the kiwifruit (Crisosto and Crisosto, 2001),

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