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Near infrared spectroscopic evaluation of fruit maturity and quality of export Thai mango (*Mangifera indica* L. var. Namdokmai)

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Abstract

Mango fruit var. Namdokmai were harvested from tagged trees at 91-119 days from full bloom at weekly intervals. Selected fruit were subjected to near infrared spectroscopy (NIRS) in reflectance mode at short wavelength of 700-1100 nm at 2 nm increments and calibrated to give predicted brix value (NIRS value). Fruit weight, firmness and dry matter content (DMC) were measured. At the ripe stage, peel and pulp color, total soluble solids (TSS), titratable acidity (TA), TSS:TA ratio and sensory taste were determined. To assess the predictability of maturity and quality parameters, linear regression models were developed. NIRS value increased with increasing fruit maturity, showed high coefficient of determination ($R^2 = 0.88$), and was positively correlated with DMC ($R^2 = 0.96$) and negatively correlated with fruit firmness ($R^2 = 0.99$). NIRS values also predicted TSS of ripe fruit with 99% accuracy. Other quality parameters had lower predictability values of 70-84%, except for fruit weight and L^* values of the peel and pulp, which had no or weak correlation with NIRS values. Based on the results, optimum harvest maturity was reached at 105-112 days from full bloom (DAFB). The present harvest maturity recommendation (91-105 DAFB) needs to be revised to reduce heterogeneity in fruit maturity and quality from the same harvest and increase quality outturn. The results further provide strong basis of the utility of NIRS facility in continuous fruit packing line as a component of the quality assurance system.

Introduction

Mango (*Mangifera indica* L.) var. Namdokmai is the main export variety of Thailand. In 2012, export volume of fresh fruit was 44,450 tons valued at about 938 million baht (US$ 31 million), with Japan, Malaysia and Korea as the major destinations (Office of Agricultural Economics-Thailand, 2013). The export market expanded but exporters could not meet demand for uniform quality fruit that increasingly considers internal attributes in addition to external appearance. High heterogeneity in quality of fruit from the same harvest is a critical bottleneck in mango production and export.

Maturity is the most important factor that determines fruit quality after harvest (Kader, 1999). Namdokmai mangoes are harvested mature green at 91-105 days after full bloom (DAFB), which is based subjectively on experience (Jutamanee *et al.*, 2002; Kienzle *et al.*, 2012). The wide range of harvest age accounts for the divergent quality of fruit from the same harvest. Some fruit not meeting export standards can be sorted out in the packhouse; this contributes to low quality outturn in the supply side of the export chain.

Recognizing the paramount role of harvest maturity in assuring fruit quality, research works have been undertaken to optimize harvest maturity and minimize variations in quality, ripening and shelf life (Sivakumar *et al.*, 2011; Neidhart, 2012). Recent studies in Namdokmai mango identified titratable acids (TA) and color hue value of the fruit pulp as the most decisive attributes specifying harvest maturity concomitant with the number of days elapsed from fruit set, while the content of chlorophyll b, total soluble solids (TSS) and dry matter content (DMC) were considered secondary maturity criteria (Kienzle *et al.*, 2012). Because of the destructive nature of some maturity indices (e.g. TSS, TA, DMC) and subjectivity of other indices (e.g. days to harvesting, color), non-destructive methods of objective assessment of fruit maturity and quality have been developed (Slaughter, 2009; Jha *et al.*, 2010; Wanitchang *et al.*, 2011; Salengke and Mursalim, 2013). These methods can be easily integrated into continuous packing lines.

Near infrared spectroscopy (NIRS) is one of the non-destructive techniques of quality evaluation that has been implemented successfully in the food industry (Folley *et al.*, 1998; Nicolai *et al.*, 2007; Slaughter, 2009; Sanchez, 2012; Magwaza *et al.*,

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2012, 2013). NIRS is accurate, reliable, rapid, non-destructive, and inexpensive. In mango, one fruit can be investigated in less than a minute without sample preparation or use of chemical (Mahayothee *et al*., 2002). In addition, this method can be performed by non-skilled operators after calibration and validation. At appropriate spectral range, NIRS can predict more than one quality or physiological parameter at the same time (Lammertyn *et al*., 1998; Schmilovitch *et al*., 2000).

NIRS has been tested on different varieties of mango (Guthrie and Walsh, 1997; Schmilovitch *et al*., 2000; Jha *et al*., 2014) including Thai mangoes (Mahayothee *et al*., 2002; Saranwong *et al*., 2001, 2003a-b). Wide spectral ranges of 400-2500 nm have been used, and dry matter and starch contents were the commonly analyzed quality attributes. In Namdokmai mango, it was found that the short wavelength region (700-1100 nm) was more suitable for quality determination because its penetration depth into the flesh was higher than that of the long wavelength region (110-2500 nm) (Saranwong *et al*., 2001). A technique was then developed to predict the ripe eating quality of the fruit using dry matter and starch contents measured by NIRS in green fruits at harvest (Saranwong *et al*., 2003a-b, 2004). A portable hand-held NIRS instrument was used and was found to be as accurate as the laboratory NIRS system. In a related study, Mahayothee et al (2002) obtained low coefficients of determination for sugar-acid ratio, TSS and TA probably due to inappropriate wavelength (650-2500 nm) used. At present, export companies are starting to adopt NIRS as part of quality assurance system. To maximize the commercial use of NIRS for non-destructive quality evaluation, this study was conducted to examine the relationship between harvest maturity and NIRS values and correlate harvest quality and NIRS value to ripe quality attributes.

Materials and Methods

Fruit sampling

Namdokmai mangoes were obtained from a commercial orchard in Chantaburi Province, Thailand. They were selected from among those tagged at full bloom, harvested at 91-119 days thereafter, and transported to a packhouse of a mango export company in the same province for NIRS analysis. Sixty fruit of uniform size and free of defects were selected from each stage of harvest maturity and brought to the Horticultural Research Centre, Chanthaburi, for furthers analysis. Fruit were ripened with ethephon at 200 ppm with 5 min dips.

NIRS analysis

An NIR spectrometer (NIRS 6500) of an export company was used in the reflectance mode at short wavelength region of 700-1100 nm in 2 nm increments (Saranwong *et al*., 2001, 2003a-b, 2004). The spectrometer was calibrated to give predicted brix value, herein referred to as NIRS value, which was automatically generated from a personal computer connected to the instrument.

Physicochemical quality analysis

At harvest, fruit weight, firmness and DMC were determined. Firmness was measured using a tension-compression gauge with 6.4 mm probe (Daiichi FG 520 K) as the force needed to penetrate 4.4 mm diameter into the flesh. DMC was determined by the oven-drying method at 72°C until constant weight.

At the ripe stage, peel and pulp color were measured with a Color Recorder CR-10 (Konica Minolta Sensing Inc., Japan) as Hunter L^* (lightness), a^* (green-red coordinates) and b^* (blue-yellow coordinates) values. TSS was determined using a hand-held refractometer (Atago). TA was analyzed by the titrimetric method using standardized 0.1 N NaOH and phenolphthalein as an indicator. TSS:TA ratio was then calculated. Sensory taste was evaluated by 30 trained panelists using a scoring of 1-5 with 1 = bad, 3 = normal taste and 5 = good taste.

Statistical analysis

Results were analyzed using the SPSS statistical package and Scheffe's multiple contrast at 95% confidence level. To determine the correlation of NIR values and harvest maturity, fruit weight, firmness and DMC at harvest and TSS, TA, TSS:TA and sensory taste at the ripe stage, linear regression models were constructed and the coefficient of determination (R^2) was calculated.

Results and Discussion

Fruit maturity and quality

NIRS values significantly increased with increasing fruit maturity from 91 DAFB to 98 DAFB (Table 1). With advancing age up to 112 DAFB, the increase in NIRS values had no statistical significance. The most mature fruit (119 DAFB) had the highest NIRS value, which was comparable to that of fruit harvested at 105-112 DAFB. Fruit maturity and NIRS values were strongly correlated with coefficient of determination (R^2) of 0.88 indicating strong linear relationship (Figure 1A). Fruit weight did not differ with maturity and was not correlated with it as well as with NIRS value (Figure

Table 1. NIRS value, fruit weight, firmness and dry matter content (DMC) of ‘Nam dokmai’ mango at different harvest maturities

Days from fruit set	NIRS value	Fruit weight (g)	Firmness (N)	DMC (%)
91	12.1c	270.9	50.4b	7.1c
98	15.0b	269.0	43.7a	8.5bc
105	15.6ab	269.4	43.1a	9.2ab
112	16.1ab	268.0	42.7a	9.9ab
119	17.3a	272.3	39.4a	10.7a
CV (%)	2.5	11.3	8.4	2.9
R^2	0.88		0.67	0.96

Means with the same letter are not significantly different at P = 0.05. CV-coefficient of variation; R^2-coefficient of determination

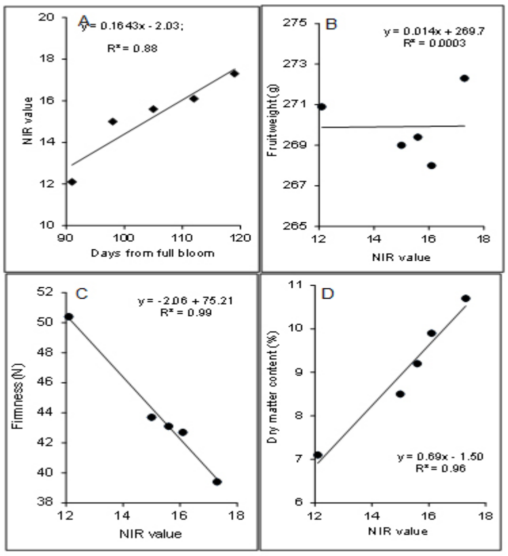

Figure 1. Linear regression models for NIRS value and harvest maturity, fruit weight, firmness, dry matter content and visual score for export (VSE) of ‘Nam dokmai’ mango at different harvest maturities.

1B). Firmness was highest in the youngest fruit (91 DAFB) and decreased in fruit at 98-112 DAFB. It was not highly correlated with maturity (R^2 = 0.67), but strongly correlated with NIRS values (R^2 = 0.99) (Figure 1C). On the other hand, DMC increased with increasing maturity and was comparably highest in fruit at 105-119 DAFB. It had strong correlation with both maturity and NIRS value with high degree of accuracy (R^2 = 0.96). Furthermore, in actual quality grading by exporting companies, Namdokmai mango with NIRS values of 13-16 were considered normal export grade, while NIRS values of 17 or higher were considered premium export grade. From Table 1, it can be seen that only fruit harvested at 91 DAFB failed to meet the NIRS value for export grade.

Previous works correlated NIRS values with DMC and maturity of different varieties of mango (Namdokmai, Chok Anan, Kensington Pride and Tommy Atkins) with R^2 ranging from 0.66-0.96 (Guthrie and Walsh, 1997; Schmilovitch *et al*., 2000; Saranwong *et al*., 2001; Mahayothee *et al*., 2004; Sivakumar *et al*., 2006). Commercial NIRS for on-line use in fruit packing lines and portable NIR instrument for orchard use similarly obtained

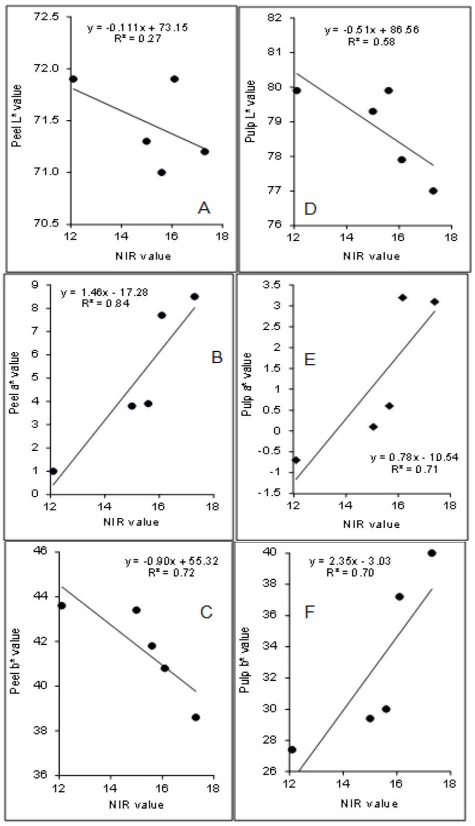

Figure 2. Linear regression models for NIRS value and color parameters of peel and pulp at the ripe stage of ‘Nam dokmai’ mango at different harvest maturities.

acceptable performance to predict DMC and maturity of mangoes (Saranwong *et al*., 2003a, 2003b; Walsh *et al*., 2004). Some of these studies also showed good correlation of NIRS values and firmness (R^2 = 0.62-0.85) supporting the possibility of non-destructive firmness assessment by NIRS (Garcia-Ramos *et al*., 2005; Subedi and Walsh, 2005). This is corroborated by the results of the present study on both firmness and DMC, which were highly correlated with maturity and NIRS values. Furthermore, it was revealed that estimating fruit weight by NIRS would be of great interest since it could be an added parameter from a single NIRS measure as shown in nectarine, orange and olives (Marin *et al.*, 2009; Cayuela and Weiland, 2010; Morales-Sillero *et al.*, 2011). The present study provided contradictory results due to lack of correlation between fruit weight, maturity and NIRS values.

NIRS and ripe fruit quality

Ripe fruit had comparable L^* values of the peel and pulp regardless of harvest maturity (Table 2). Similarly, peel yellowing (b^*) did not differ significantly with maturity. In contrast, pulp yellowing was more intense in fruit at more mature stage at harvest, although it was comparable among fruit harvested at 98-119 DAFB. Coefficient of

Table 2. Peel and pulp color parameters at the ripe stage of 'Nam dokmai' mango at different harvest maturities

Days from fruit set	Peel Color			Pulp Color		
	L*	a*	b*	L*	a*	b*
91	71.9	1.0c	43.6	79.9	-0.7b	27.4b
98	71.3	3.8b	43.4	79.3	0.1b	29.4ab
105	71.0	3.9b	41.8	79.9	0.6b	30.0ab
112	71.9	7.7a	40.8	77.9	3.2a	37.2ab
119	71.2	8.5a	38.6	77.0	3.1a	40.4a
CV (%)	3.3	40.9	4.5	3.0	14.7	2.8
R^2		0.88			0.81	0.83

Means with the same letter are not significantly different at P = 0.05. CV-coefficient of variation; R^2-coefficient of determination

Table 3. Total soluble solids (TSS), titratable acidity (TA), TSS:TA, and sensory taste at the ripe stage of 'Nam dokmai' mango at different harvest maturities

Days from fruit set	TSS (°B)	TA (% malate)	TSS/TA	Taste[a]
91	9.7c	0.31a	31.3e	2.1c
98	13.1b	0.30a	43.7d	2.5c
105	14.8ab	0.22b	67.3c	3.0bc
112	15.3ab	0.14c	109.3b	4.0ab
119	16.0a	0.13c	129.2a	4.1a
CV (%)	2.9	13.1	10.3	8.2
R^2	0.83	0.86	0.94	0.90

[a]Sensory taste score: 1 = bad, 3 = normal taste, 5 = good taste
Means with the same letter are not significantly different at P = 0.05. CV-coefficient of variation; R^2-coefficient of determination

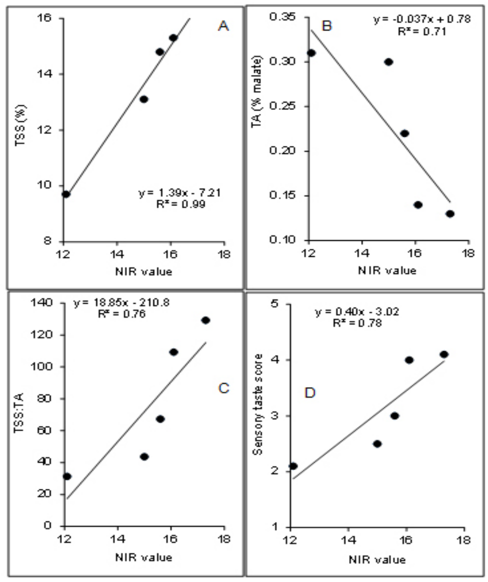

Figure 3. Linear regression models for NIRS value and total soluble solids (TSS), titratable acidity (TA) and sensory taste at the ripe stage of 'Nam dokmai' mango at different harvest maturities.

determination was more than 0.8, indicating high degree of predictability of pulp yellowing in relation to harvest maturity. This was also obtained for a^* values for both peel and pulp, which increased with increasing harvest maturity. Linear regression models show very low correlation between NIRS values and L^* of peel and pulp (R^2 = 0.27-0.58) (Figure 2C, 2D), but for a^* or b^* values, fairly high correlation (R^2 = >0.7) was obtained (Figure 2B-F).

Mango pulp color has been considered as one of the most consistent objective methods of determining mango maturity that can be predicted using the NIR properties of the fruit (Slaughter, 2009). Subedi *et al.* (2007) found that pulp color (b^* value) was a better index of 'Kensington Pride' mango maturity than DMC. This is in contrast to the present results. While there was good correlation for pulp b^* (yellowing) and maturity or NIRS values (R^2 = 0.70-0.83), better correlation for DMC was obtained (R^2 = 0.96).

In terms of chemical and sensory quality, strong relationship was found between harvest maturity and ripe fruit TSS, TA, TSS:TA ratio and sensory taste, which all increased with increasing harvest maturity (R^2 = 0.83-0.94) (Table 3). These quality parameters were highest in the most mature fruit (119 DAFB); only fruit harvested at 112 DAFB compared well in terms of TSS, TA and sensory taste. NIRS values were most predictive of TSS (R^2 = 0.99) (Figure 3A) compared to TA, TSS:TA ratio and sensory taste (R^2 = <0.8) (Figure 3B-D).

TSS and TA are the main chemical parameters of fruit quality and its relation is frequently used as maturity index (Sanchez, 2012). NIRS analysis of TSS of intact fruit has been done in a number of fruits including mangoes with R^2 ranging from 0.59 to 0.93 (Guthrie and Walsh, 1997; Schmilovitch *et al*., 2000; Mahayothee *et al.*, 2004; Sivakumar *et al*., 2006). Much higher R^2 was obtained in the present study and related well with that for DMC at harvest. Saranwong *et al.* (2004, 2005) also obtained high correlation between NIRS values and DMC on mangoes scanned at harvest and predicted TSS of the fruit when ripe based on a linear model (R^2 = 0.85). This was further done by Subedi *et al.* (2007) and the linear model using the NIR spectra obtained at harvest was used to predict TSS of the fruit when ripe (R^2 = 0.90). On the other hand, NIRS prediction of TA has been considered difficult to achieve on intact fruit, due to its relatively low levels of organic acids (McGlone *et al*., 2003; Guthrie *et al.*, 2005).

TSS:TA ratio is the key to consumer acceptability and is widely used also as maturity criterion for most fruit. It has been suggested that when the target of NIRS analysis is the TSS:TA ratio as maturity index, direct prediction of this parameter could bring better results than their separate analysis, as has been demonstrated in oranges (Cayuela and Weiland, 2010). This was not, however, the case for Namdokmai mangoes as TSS alone could be predicted based on NIRS values with much higher accuracy than TSS:TA ratio.

Sensory quality measurement is a newer area of NIRS analysis (Serrano and Lopez, 2006). Some sensory attributes could be successfully predicted by NIRS because of these attributes, such as sweetness, which are directly correlated with TSS and consumer acceptance (Sanchez, 2012). Sensory attributes of mango has been reported as NIRS predictable (Saranwong *et al*., 2004). In the present study, there seemed to be good predictive relationship between sensory taste and NIRS values ($R^2 = 0.78$).

Optimum harvest maturity

Considering all quality parameters at harvest and at the ripe stage, fruit were at optimum maturity at 105-112 DAFB. This was predicted by NIRS analysis is strongly correlated with optimum firmness and DMC at harvest (Table 1; Figure 1C-D) and TSS at the ripe stage and fairly correlated with pulp yellowing and sensory taste (Table 2-3; Figure 2F; Figure 3D).

It has been reported that Namdokmai mangoes are usually harvested mature green at 91-105 DAFB (Jutamanee *et al*., 2002; Kienzle *et al*., 2012). Using this recommendation could result in more fruit with lower degree of maturity and less desirable taste at the ripe stage. In addition to determining and confirming fruit are mature for harvest, NIRS system could be employed as part of the packing line to segregate more mature and high-DMC fruit. This will ensure good internal attributes of fruit for export.

Conclusion

Mango fruit maturity attributes were successfully predicted using NIRS. NIRS values correlated very strongly with firmness and DMC at harvest and predicted TSS with very high accuracy. Other quality parameters had lower predictability values or R^2 ranging from 0.70-0.84, except for fruit weight and L^* values, which had no or weak correlation with NIRS values. Optimum harvest maturity was reached at 105-112 DAFB, highlighting the need to use the upper limit of the present harvest maturity recommendation (91-105 DAFB) to ensure good internal attributes in addition to attractive fresh appearance. As part of quality assurance system, NIRS facility could be integrated in continuous fruit packing line.

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