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Nondestructive prediction of maturity of mango using near infrared spectroscopy

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ABSTRACT

This study proposes a formula for prediction of maturity index (I_m) using physico-chemical characteristics and overall acceptability (OA) of a sensory panel for mangoes from orchards of nine Indian states. Computed I_m values were found to be in agreement with both OA scores and the perceptions of experienced farmers. NIR spectra of 1180 mangoes were acquired. Multiple-linear regression (MLR) and partial least square (PLS) models were developed in the wavelength range of 1200–2200 nm to predict I_m. The best prediction was achieved using PLS model after MSC data treatment in the wavelength range of 1600–1800 nm. Multiple correlation coefficients (R) for calibration and validation of PLS model were 0.74 and 0.68, respectively. Lower difference in standard errors of calibration (0.305) and prediction (0.335), indicated the potential of NIRS in prediction of the maturity non-destructive.

1. Introduction

Mango (*Mangifera indica* L.), is an important tropical fruit marketed throughout the world (Schmilovitch et al., 2000). India is the largest producer contributing about 50% of the total world production (Anonymous, 2006). India exported around 65,000 tons of mangoes in 2010 (APEDA and Processed Food Products Export Development Authority, 2011) and the same is expected to rise in the coming years (Jha et al., 2010b). Mango is generally harvested a little earlier than the fully mature stage to avoid the onset of climacteric respiration during transportation to distant markets (Jha et al., 2007). It is consumed both in fresh and processed form. Bulk of it, in majority of mango producing countries, is consumed as fresh fruit (Mtebe et al., 2006). It is also used by processing industries for making numerous processed products. The products prepared from both ripe and green mangoes are highly popular in India and abroad (Jha et al., 2010a). The maturity level of harvest plays an important role in deciding their end use. Selection of fruit with proper degree of maturity is also a first step towards quality assurance (Schmilovitch et al., 2000) and is dependent on physico-chemical quality parameters such as total soluble solids (TSS), pH, titratable acidity (TA), and dry matter (DM). The existing methods of maturity estimation entail subjective variations and lead to harvest of mature and under mature mangoes. Harvesting at immature stage leads to fruits with uneven ripening, excessive shriveling and low levels of sweetness and flavour. Late harvested fruits, on the other hand, result in reduced shelf life with greater susceptibility to spoilage (Jha et al., 2007). Mature green mango with fair hardness attains a better eating quality during ripening (Medlicott et al., 1988). Digitized prediction of maturity therefore is of considerable importance for both export and for reducing huge post-harvest losses. Knowledge of computing and prediction of maturity will also help in devising marketing, transport and storage strategies. Most consumers rely on surface firmness, gloss, aroma, flavour, and other physiological parameters to determine the quality which is often misleading. So the demand for easy, rapid and nondestructive evaluation of quality parameters has gained momentum in past few decades (Jha and Matsuoka, 2000). Nondestructive methods are widely explored to predict the quality of fruits (Dull et al., 1992; Slaughter, 1995; Jha and Garg, 2010). Many physical characteristics of fruits and vegetables have been determined using nondestructive techniques (Lesage and Destain, 1996). Nuclear magnetic resonance (NMR), X-ray and computed tomography, Near infrared spectroscopy (NIRS), electronic nose, machine vision and ultrasound are some of the most recent techniques used for nondestructive quality evaluation of foods (Narsaiah and Jha, 2012). All these techniques are rapid and non destructive. NIRS, however, is gaining wider acceptance due to its cost effectiveness, ease of operation and on-line applicability. Maturity and sweetness of some mango cultivars based on single property such as firmness and TSS have been predicted with reasonable accuracy and rapidity using visual and near infrared (NIR) spectroscopy (Schmilovitch et al., 2000; Sirinnapa et al., 2001, 2004; Jha et al., 2004, 2005, 2006, 2007). The objectives of this study were therefore to develop a robust formula for maturity indices combining major physico-chemical parameters and overall

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acceptability of seven major cultivars of mango and predict the same using NIR spectroscopy.

2. Materials and methods

2.1. Sample collection

Orchards of seven cultivars (*Chausa, Langra, Kesar, Neelam, Dasheri, Mallika and Maldah*) from different mango growing states of India (Maharashtra, Odisha, Punjab, Uttar Pradesh, Bihar and Tamilnadu) were selected. Each orchard was divided into four blocks. One tree from each block in north, south, east and west direction and one from the centre of the orchard was selected using randomized block design. One fruit randomly from each side and one from centre of tree canopy with stalk (8–10 mm) were plucked manually in the forenoon on three different dates during 2009 and 2010. Three harvesting dates for each cultivar, based on previous experience and suggestions of the orchard owners, were staggered to collect relatively immature, mature and over mature mangoes (Jha et al., 2006). The samples collected on first, second and third harvests in sequence were designated as early, mid and late harvest, respectively. The fruits were transported to laboratory within 48 h in well ventilated corrugated fiber board boxes (Jha et al., 2010a). Partially frozen gel packs were placed in between the layers of mangoes to minimize the quality losses.

Twenty mangoes of each cultivar, free from any external injury/blemish and of visually similar in size and colour, were sorted, destalked and desapped. Five sorted fruits of each cultivar were used for experimentation on day zero. Rest of the mangoes were then stored under ambient conditions (26–30 °C, RH 60–70%) for natural ripening. Wider range of temperature was due to climatic fluctuation during the period of 4 months of experiments for different cultivars. Three fruits of each cultivar were used for experiments on alternate day of 10 days storage period.

2.2. NIR spectra acquisition

The NIR spectra were acquired using a portable NIR spectrometer (Luminar 5030, Brimrose Corp., Maryland, USA), equipped with a diffuse reflectance optical configuration and an InGaAs detector (1200–2200 nm). The spectrometer included a measurement unit connected to a computer. The configuration of the system was similar to that described by Jha et al. (2012). Each fruit was scanned 50 times in the sampled region and averaged as one spectra. A total of four spectra, from two equidistant points along the equatorial region of both sides of fruit, were acquired, averaged and stored for analysis.

2.3. Determination of physico-chemical properties

The physical dimensions of fruits, viz. length (L), width (W) and thickness (T) were measured using a digital vernier caliper gauge (Mitutoya, Japan; Least count 0.01 mm). The arithmetic mean diameter (d_a), geometric mean diameter (d_g), sphericity (Ø) and aspect ratio (R_a) were computed using standard formulae (Jha, 1999; Jha and Prasad, 1993). The pulp of mango fruit, from the region of NIR spectra acquisition, was scooped and macerated in mortar and pestle followed by centrifugation (Eltek MP-400R, Electrocraft, Mumbai, India) at 15,000 rpm for 5 min to get clarified juice. The clarified juice was filtered using new piece of muslin cloth to remove suspended solids. The TSS and pH of juice were measured thrice (Jha and Matsuoka, 2004) using a handheld digital refractometer (PAL-1, Atago Japan; range 0–53 °Brix, least count 0.2 °Brix) and digital pH meter (Thermo Fisher Scientific Inc., Singapore), respectively, and the average values were noted. DM of pulp and TA of clarified juice were determined using standard methods (AOAC, 1995).

2.4. Sensory evaluation

Sensory evaluation of naturally ripe mangoes was conducted in the nondestructive quality evaluation laboratory of the Central Institute of Post-Harvest Engineering and Technology, Ludhiana, India by a panel of ten semi-trained judges comprising of equal male and female members. Fruit was cut into small pieces from equatorial region to get ten pieces and each was presented before the panelists in three digit-coded plates covered with lids at room temperature and under normal lighting conditions. Each sample was prepared in less than 5 min before the sensory testing so as to maintain the glossy aspect and to avoid browning. The panelists opened the lid of the plate containing fruit sample and rated the sample for various sensory attributes, i.e. appearance, taste and flavour on nine-point Hedonic scale (9 = like extremely, 8 = like very much, 7 = like moderately, 6 = like slightly, 5 = neither like nor dislike, 4 = dislike slightly, 3 = dislike moderately, 2 = dislike very much and 1 = dislike extremely) (Lawless and Heymann, 1998). Distilled water was provided to panelists after rating of each sample to rinse their mouth and palate (Mtebe et al., 2006). Overall acceptability (OA) was calculated using average value of appearance, taste and flavour score.

3. Results and discussion

3.1. Formulation of maturity index (I_m)

From the trends of OA score in Fig. 1 and widely accepted views in literature, following guidelines were set to help in formulation of maturity index: (i) I_m is a function of different physico-chemical parameters; (ii) I_m increases continuously with harvesting stage; (iii) overall acceptability (OA) and shelf life of ripe mangoes increase with increase in I_m till its value reaches near to one; (iv) OA and shelf life of mangoes having I_m more than one at harvest decreases after six days of natural ripening; and (v) An OA score of six, which represents 'liked slightly' on the Hedonic scale, was cut off value taken on or after the sixth day of natural ripening.

Different combinations based on previous experiences (Jha et al., 2007, 2012; Jha and Matsuoka, 2002) were used to formulate empirical expressions for I_m. The I_m values were computed putting the measured values of physico-chemical parameters in the developed expressions (Table 1). Trends of computed I_m values and OA score were studied in context of assumption (iii) above and a typical graphical representation (Fig. 1) indicates OA score at zero day (i.e. the day of harvesting) was very low for early harvested mangoes as compared to that of mid and late harvest ones. It also took longer time (6 days for ripening) to reach the threshold OA value of six as compared to that of one day for both mid and late harvested mangoes. The total number of days (i.e. shelf life) during ripening for which mangoes were acceptable were lowest (5 days) for early harvested and the highest (10 days) for mid harvested one. OA score however on the 10th day of ripening was highest (>6) for early harvested mangoes and the lowest (<6) for the late harvested samples. The late harvested mangoes probably were over mature and thus over ripened soon resulting in lower shelf life.

The twenty expressions (Table 2) supporting the assumptions and fitting to trends of OA score were screened for field testing. The samples having the range of I_m between 0.8 and 1.2 computed by formula (Eq. (1)), were categorized as mature. Mangoes having I_m values less than 0.8 were categorized as immature and those with I_m values more than 1.2 were categorized as over mature

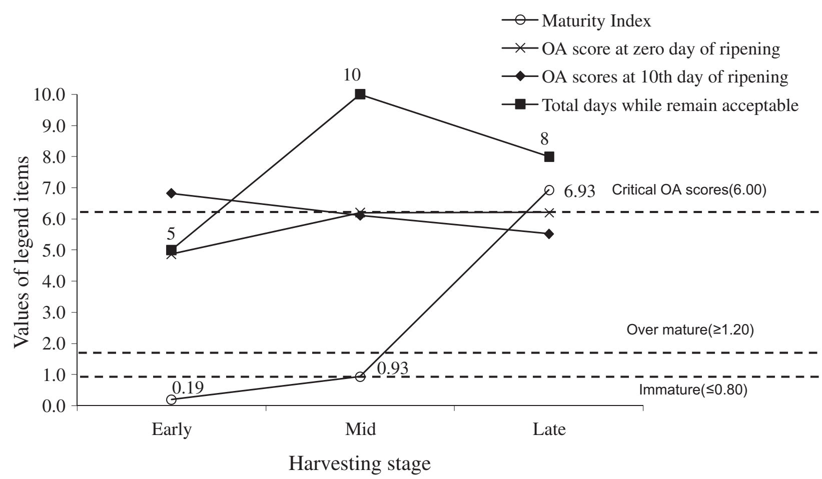

Fig. 1. Typical variations in OA, shelf life and maturity index during natural ripening.

Table 1
Ranges, mean and standard deviations of physico-chemical quality parameters used in formulation of maturity index.

Parameters	Maximum	Minimum	Mean with SD
TSS (°Brix)	31.6	1.76	14.9 (4.98)[a]
pH	6.65	2.22	3.81(1.01)
TA (%)	7.26	0.065	1.30(1.21)
DM (%)	49.04	5.84	22.59(5.61)
d_g (mm)	74.92	60.22	68.12(5.26)
d_a (mm)	77.21	61.33	70.49(5.34)
R_a	92.09	65.07	84.79(7.53)
Ø	0.84	0.63	0.74(0.06)

[a] d_a and d_g are arithmetic and geometric mean diameter; R_a is aspect ratio and Ø is sphericity: figures in parenthesis are standard deviation.

Table 2
Preliminary screened expressions for maturity index.

S. No.	I_m
1	(TSS × pH × Ø)/DM
2	(TSS + TA + DM)×(pH × Ø/d_g)
3	(TA × (TSS + pH)/(d_g × Ø)
4	(TSS × DM)/(pH × d_g)
5	(d_g × Ø)/(DM × pH)
6	(TSS × pH × TA × Ø)/(DM + d_g)
7	(pH × TA)/TSS
8	(DM + TA) × pH/d_g
9	(TSS/(pH × TA × Ø)
10	(TSS × pH × TA × DM)/(d_g × Ø × d_a)
11	(pH × d_g × Ø)/R_a
12	(d_a × pH × TA × Ø)/(d_g × TSS)
13	(TA × DM × Ø)/(d_g)
14	(Ø × TSS × DM)/(d_g × pH)
15	(TSS × d_a)/(d_g × pH × TA)
16	(d_g × TSS × Ø)/(pH × TA × d_a)
17	(d_g × TSS)/(pH × TA × d_a)
18	(DM × TSS)/(d_g × TA × Ø)
19	(TSS × DM)/TA
20	(TSS × DM × pH)

(Fig. 1). A formula (Eq. (1)) followed the trend of OA score closely was thus selected for field testing.

$$I_m = \eta \frac{TSS \times DM}{TA} \quad (1)$$

where I_m, TSS, DM, TA and η are maturity index, total soluble solids contents (°Brix), dry matter content (%), titratable acidity (%) and constant specific for each cultivar and region of its production, respectively.

3.2. Field validation of I_m

A multilocational survey to test the efficacy of developed expressions for maturity index was conducted in different orchards of Punjab and Uttar Pradesh in the third year (2011) of experimentation. Five samples for each variety (Table 3) were randomly plucked and their maturity as perceived by experienced orchard owner was noted down. I_m values using Eq. (1) were computed after measuring each physico-chemical parameter in orchard itself and compared the same with the values based on farmers' perceptions. The percent deviation (Table 3) for the best performing formula (Eq. (1)) was less than 10% in majority of cases, except in two instances of *Dashehri* and one instance for *Langra* cultivars, which may be due to subjective variations in experience and perception of the farmers. Lower variations in all other cases indicated that the performance of the developed formula (Eq. (1)) was satisfactory.

An additional six samples of each cultivar, covering different maturity levels, were collected in third year and stored in laboratory as described in sampling section for ripening and predicting the I_m using NIR.

3.3. NIR modeling

Spectral data were imported to Unscrambler (CAMO AS, Trondheim, Norway, version 10x) software for multivariate analysis with maturity indices. Data were plotted to inspect the nature of the spectra in the wavelength range of 1200–2200 nm. The spectral curves did not show any specific varietal differences visually. The peaks and depressions however, showed the strong and weak transmittance characteristics of the mangoes, in the wavelength range of the 1600–1800 and 1400–1600, respectively (Fig. 2a). The relative values in the other regions of the spectra, however, differed from sample to sample which might be due to change in surface texture and moisture content of stored mango. Such variations, in case of apple have also been reported in other studies (Jha and Garg, 2010). Altogether 1180 spectra were used in calibration and validation for prediction of maturity index.

Two methods of regression, partial least square (PLS) regression and multiple linear regression (MLR) with the option of full cross validation, were performed on the original spectra to develop NIR models for predicting maturity non-destructively. The whole range of spectra was divided into groups of 200 wavelengths continuously and both PLS and MLR were performed on each group to search for a simple model. The best models based on the standard

Table 3
Comparison of computed maturity index with that of farmers' perception.

Location		Cultivars	Farmers' estimate[a]	Computed I_m[a]	Percent deviation
Punjab	Gurdaspur	Chausa	1.00 ± 0.02	1.00 ± 0.02	0.00
		Dashehri	0.30 ± 0.03	0.40 ± 0.04	−33.33
		Dashehri	0.70 ± 0.02	0.75 ± 0.03	−7.14
	Patiala	Chausa	0.50 ± 0.02	0.50 ± 0.02	0.00
		Dashehri	0.90 ± 0.05	1.00 ± 0.04	−11.11
UP	Bijnor	Langra	1.00 ± 0.03	1.00 ± 0.05	0.00
		Langra	0.85 ± 0.05	1.00 ± 0.05	−17.64
	Saharanpur	Chausa	0.30 ± 0.02	0.32 ± 0.02	−6.66
		Dashehri	0.50 ± 0.03	0.60 ± 0.03	−20.00
		Langra	0.50 ± 0.03	0.52 ± 0.05	−4.00

n = 5 mangoes;
[a] mean ± standard deviation.

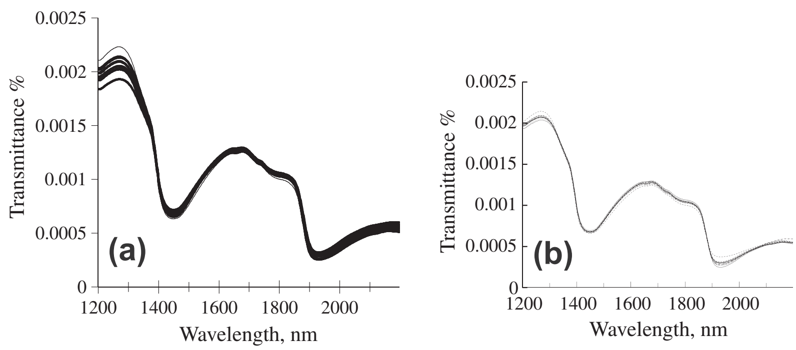

Fig. 2. Typical NIR spectra of different varieties of mango in wavelength range of 1200–2200 nm original and MSC treated.

Table 4
Statistical parameters of the developed NIR model for predicting the developed I_m.

No. of samples	Regression analysis	Wavelength range	Data preprocessing technique	Calibration			Validation		
				R	SEC	Bias	R	SEP	Bias
1180	PLS	1600–1800	None	0.72	0.313	0.00	0.68	0.330	0.024
			Smoothening	0.72	0.316	0.00	0.68	0.331	0.022
			MSC	0.74	0.305	0.00	0.68	0.335	0.014
			Second order derivatives	0.72	0.313	0.00	0.67	0.337	0.019
			Baseline correction	0.73	0.310	0.00	0.68	0.333	0.023
	MLR	1600–1800	None	0.94	0.154	−0.02	0.70	0.316	0.012
			Smoothening	0.93	0.167	0.76	0.59	0.365	0.034
			MSC	0.94	0.148	0.18	0.70	0.306	0.013
			Second order derivatives	0.93	0.163	0.00	0.64	0.339	−0.007
			Baseline correction	0.94	0.153	0.01	0.70	0.318	0.015

error of calibration (SEC), multiple correlation coefficients (R) and standard error of prediction (SEP) were selected (Jha et al., 2005, 2006).

In order to improve the predictability of selected models, pre-processing of spectra such as baseline correction, smoothing, full multiplicative scatter correction and second order derivatisation of selected range of wavelengths were performed. Scatter plots of measured and predicted maturity indices were plotted to know the goodness of prediction.

3.4. Selection of NIR model

Multiple correlation coefficient (R) for calibration and validation of I_m using both PLS and MLR models were found to be invariably higher for each cultivar in wavelength range of 1600–1800 nm as compared to that in other ranges of wavelengths. The calibration model could be slightly improved using pre-processing techniques (Table 4) such as baseline corrections, smoothing, second order derivatives and multiplicative scatter corrections (MSC) (Jaiswal et al., 2012; Jha et al., 2012a,b). The best results however were obtained for spectral data treated with multiplicative scatter correction (Fig 2b). Maximum values of R for calibration and validation of maturity for PLS model were found to be 0.72 and 0.68, respectively for the wavelength range of 1600–1800 nm, whereas in case of MLR, these values were 0.94 and 0.70, respectively (Table 4). The standard error of calibration and validation of PLS model were found to be 0.305 and 0.335 (in terms of RSD 0.248 and 0.265), respectively. The low SEC, SEP values and lower difference in them indicates better accuracy and stability, respectively in prediction. The MLR model is having better R values for calibration but lower R values for prediction. The large difference in R values may cause instability during prediction. Jha and Garg (2010), also reported larger difference in R values of calibration (0.749) and validation (0.457) with MLR model as compared to PLS model (0.562 and 0.454, respectively) for prediction of TSS of apple. The R values in this case are slightly lower for PLS model as compared to some reported in literature (Saranwong et al., 2001,2004). This is expected because the present model is built by combining multiple param-

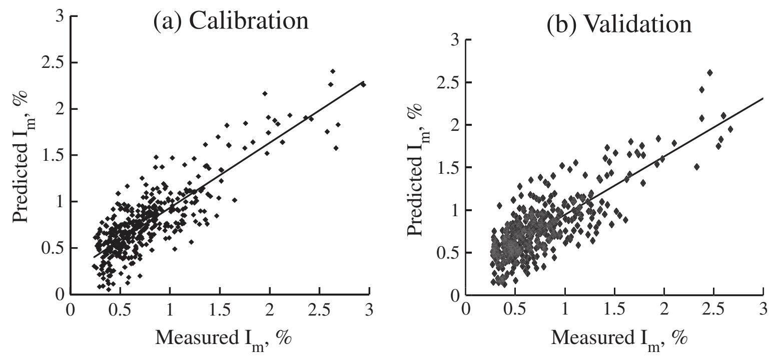

Fig. 3. Scatter plots of calibration and validation for computed I_m.

Table 5
Comparison of computed and NIR predicted I_m.

	Chausa Punjab	*Chausa* Uttar Pradesh	*Dashehri* Punjab	*Dashehri* Uttar Pradesh	*Kesar* Gujarat	*Kesar* Maharashtra	*Langra* Uttar Pradesh	*Maldah* Bihar	*Mallika* Orissa	*Neelam* Tamil Nadu
NIR predicted	0.688	0.678	0.313	0.645	1.835	0.500	0.628	0.900	0.420	0.250
Computed	0.688	0.763	0.284	0.694	1.789	0.443	0.685	0.844	0.384	0.331
Deviation (%)	0.00	11.19	−10.23	7.09	−2.57	−12.89	8.39	−6.58	−9.38	24.36

n = 36 (6 for each cultivar).

eters of many cultivars to have robustness in model for wide range of cultivars. The previous reports are applicable only for single cultivar based on single parameter. The present model is therefore having wider commercial applicability than the earlier one. Lower difference in both the R values indicates that maturity of seven major cultivars (*Chausa, Langra, Kesar, Neelam, Dasheri, Mallika* and *Maldah*) could be predicted with reasonable repeatability using PLS model. Slope and uniform distribution of samples in scatter plots (Fig. 3) indicated that the predicted values are closer to actual ones; thus the NIR model was selected for further validation in field tests.

Previous reports of determining maturity of different mango varieties e.g. 'Thai mangoes' (Mahayothee et al., 2004); 'Mahajanaka' (Saranwong et al., 2003 and 2005); and 'Tommy Atkins' mangoes (Schmilovitch et al., 2000) were based on modelling of physico-chemical parameters such as starch content and dry matter, TSS, acidity individually with NIRS of respective mango cultivar. In contrast, the present work focuses on hitherto unexplored approach of formulation of maturity index applicable to seven mango cultivars, with multiple parameters to reflect their interrelationship and prediction of that index non-destructively with NIRS modelling.

The $I_{m,}$ predicted using the above built NIRS model for the 42 additional samples collected in third year, was compared with their actual values based on physico-chemical parameters (Eq. (1)). The maximum variation between computed and NIR predicted I_m is 11% except in case of *Neelam* cultivar (Table 5). Lower variation in predicted and actual values as compared to that in existing subjective method indicates the suitability of I_m formula and its NIRS prediction model for practical use.

4. Conclusions

A simple maturity index (I_m) based on physico-chemical properties of seven cultivars of mangoes was formulated and field tested with less than 10% variation in case of majority of cultivars under study. The NIR model was developed to predict the computed I_m. PLS models could successfully predict the I_m in the wavelength range of 1600–1800 nm with R values of calibration and validation of 0.74 and 0.68, with residual standard deviation as 0.248 and 0.265 for calibration and validation, respectively. Field validation of prediction using the developed NIR model indicated less than 11% variations for majority of cultivars and thus may be put for practical use.

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