Assessment of in-line and hand-held sensors for non-destructive evaluation and prediction of Dry Matter content (%) and flesh color (hue°) in mango fruits

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1. Introduction

The stage of maturity of mango fruits at the time of harvest is crucial for the eating quality of ripe fruits. Selection of the appropriate matured fruit can be based on several physicochemical properties, such as dry matter content (DM), soluble solids content (SSC), skin and flesh color, and firmness, among others. The development and use of rapid, reliable, and non-destructive methods/instruments for quality evaluation of mango fruit is important to the mango industry for international trade. In this sense, several research works has been carried out in order to assess capabilities of devices based on NIR spectroscopy technique for determining non-destructively physical properties, such as DM, firmness, and SSC. Subedi et al. (2013) carried out a research work where the determination of optimum maturity stages of mangoes using fruit spectral signatures was assessed by using a hand-held NIR equipment to monitor DM content and flesh color of mango fruits maturity while on the tree. They stated that the information obtained from the NIR device can be utilized to monitor fruit maturity on the tree and in the packing line. The calibration model was robust enough for DM (R>0.96, with RMSECV<0.6% DM). Besides, the ripe stage eating quality of fruits can be predicted in its green stages. McGlone and Kawano (1998) used NIR spectroscopy to test if postharvest ripeness and physicochemical properties of kiwifruit could be determined non-destructively, by means of models for predicting firmness, DM, and SSC from NIR interactance measurements using a narrow spectral range from 800 to 1100 nm. Their results showed that DM and SSC could be predicted with good accuracy (R^2 = 0.90, RMSEP = 0.42% for DM; R^2 = 0.90, RMSEP = 0.39 °Bx for SSC). Schmilovitch et al. (2000) studied whether the use of NIR spectrometry in measuring physiological properties of intact mango fruit (cv. Tommy Atkins) was suitable for establishing relationships between non-destructive NIR spectral measurements and the major physiological properties and quality indices of mango fruit. Their results showed that non-destructive NIR measurements provided good estimates of the maturity indices of mango fruits, especially the TSS (R^2 = 0.92). Delwiche et al. (2008) determined the potential of NIR spectroscopy to predict SSC in mango. In this study, mature mangoes at 15 and 20°C were measured by NIR interactions (750-1088nm) over an 11-day period, starting when the fruit were under ripe and extending to a few days past optimal ripeness. Results showed that this technique was suitable for screening and grading mangoes and in quality evaluation at wholesale and retail levels. From the other hand, Costa et al. (2008) developed a hand-held instrument based on vis spectroscopy which allows the operator evaluate the harvest index. They stated that the most suitable harvest index in the orchard is the ground color of the skin. However, in some genotypes it is not possible to distinguish the ground color on the skin from early stages of fruit development, so the absorption of chlorophyll (I_{AD}) could be a reliable method for determining real ripeness stage. The hand-held vis spectroscopy-based is called DA-meter, which by using absorbance within the chlorophyll active range, allows indirect determination of the chlorophyll content in the fruit skin through non-destructively. In this work, sensors based on both NIR and vis spectroscopy were tested. Sensors based on NIR spectroscopy, called in-line sensor, were mounted on a packing line, while that based on vis spectroscopy was portable. The main goal was to evaluate sensors in order to assess reliability and quality of prediction, in terms of DM content and flesh color hue.

2. Materials and Methods

2.1. Fruit material

Fruit from three mango (*Mangifera* indica) cultivars growing in Mexico were used for this study. All fruit was bought to a distributor at the receiving point in the US during the summer of 2014. The cultivars tested were 'Tommy Atkins', 'Ataulfo', and 'Keitt'.

2.2. Experimental procedure

Two campaigns of experiments were carried out using cultivars mentioned above. Two 300-specimen batches of 'Tommy Atkins' and 'Ataulfo' were used during the first campaign, while one 500-specimen batch of 'Keitt' was assessed during the second one.

Several steps were carried out before measuring quality parameters in specimens. Firstly, spectra from each side of each specimen were collected by using two in-line sensors mounted on a semi-industrial scale packing line, located in Compac facilities (Visalia, CA). In-line sensors were identified as T1 (transmission) and R2 (reflection). Spectra collection was carried out by using 200 numbered specimens of 'Tommy Atkins' and 'Ataulfo' and 400 ones of 'Keitt' cultivars. Each specimen was individually placed on a cup of the packing line (5 fruits/second velocity) and sensors collected spectra when specimens run under them. After that, specimens were carefully organized in boxes.

Secondly, the DA-meter instrument was used for taking non-destructive I_{AD} measurements at KARE. These measurements consisted on taking two consecutive measurements in the equatorial zone of each cheek. The instrument was configured for calculating the average value of each pair of measurements.

Finally, destructive analyses were carried out in order to obtain real values of variables to evaluate: DM content and flesh color. By means of a slicer, pieces of skin of both cheeks were removed. Then, flesh color was measured by means of a CR-300 colorimeter (Minolta, Tokyo, Japan). The space color used was Lab (CIELAB), defined by the CIE (International Commission for Illumination). It was selected this color space because it is very easy to calculate chroma (C*) and hue angle (°) from coordinates 'a' and 'b'. Chroma and hue are usually used to characterize changes in skin & flesh color from green to yellow during ripening. Finally, a 27mm-diameter, 10mm-deep flesh core per cheek was extracted from the same place where non-destructive and flesh color measurements were collected and weighted. Cores were dried by using several dehydrators at the temperature of 46°C during 48 hours. After drying time, DM content was calculated according to the following formula.

$$DM\ (\%) = 100 - \left[\left(\frac{F-D}{F}\right)\cdot 100\right]$$

where, F and D mean fresh weight and dried weight in grams, respectively.

2.3. Data analysis

Spectra and real values were gathered and prediction models were built by Taste Technologies (New Zealand) for each mango cultivar. Linear regression models between in-line sensors predictions and the real values of DM content and flesh color were calculated using regression analysis (STATISTICA for Windows software, StatSoft Inc., 1995) on calibration data sets.

DA-meter data and real values were gathered and discrimination analyses were built (RStudio for Windows software, RStudio, Inc., 2009-2013). Segregation categories were established in accordance to previous DM contents criteria established by Crisosto and Crisosto (2012). Limits of classes for DM and DA-meter for three cultivars are showed in Table 1.

Cultivar	Limits of class	
	DM (%)	DA-meter
Tommy Atkins	< 13	< 0.75
	13 – 16	0.75 – 1.5
	> 16	>1.5
Ataulfo	< 14.5	< 0.75
	14.5 – 17	0.75– 1.5
	> 17	> 1.5
Keitt	< 13	< 0.75
	13 – 16	0.75– 1.5
	> 16	> 1.5

Table 1. Limits of classes for discrimination analysis.

3. Results

3.1. In-line sensors

Coefficients of correlation (R^2), standard errors of prediction (SEP) and root mean standard errors of prediction (RMSEP) are showed in Table 1. If results of both in-line sensors are compared, it can be observed that 'R2' sensor achieved the best results for 'Tommy Atkins' and 'Ataulfo'. However, no results are available for cultivar 'Keitt' with 'T1' because this sensor did not work properly during the second campaign of experiments. Correlations between predicted and calculated values are showed in Figures 1, 2, and 3.

It was possible to segregate mango fruits as a function of DM content (%) and flesh hue by using in-line sensors. 'Ataulfo' and 'Tommy Atkins' cultivars were segregated as a function of DM content (%) with 76% of effectivity, while 'Keitt' cultivar was segregated with 63%. In terms of flesh color, 'Ataulfo' and 'Tommy Atkins' cultivars were segregated with 66% and 64% of effectivity respectively. However, segregation of 'Keitt' cultivar was not good enough (39%).

Sensor	**Transmission (T1)**			**Reflection (R2)**		
Parameter	R^2	SEP	RMSEP	R^2	SEP	RMSEP
Ataulfo						
DM (%)	0.75	1.29%	1.50%	**0.76**	1.01	2.39
Hue°	0.56	1.38%	1.73%	**0.66**	1.21	1.22
T. Atkins						
DM (%)	0.44	0.98	1.13	**0.76**	0.66	6.63
Hue°	0.41	1.86	1.87	**0.64**	1.51	4.82
Keitt						
DM (%)	-	-	-	**0.63**	1.06	1.23
Hue°	-	-	-	**0.39**	1.54	1.59

Table 2. R^2, SEP, and RMSEP for DM content (%) and flesh color (hue°) models (cvs. 'Ataulfo', 'Tommy Atkins', and 'Keitt') for T1 & R2 sensors.

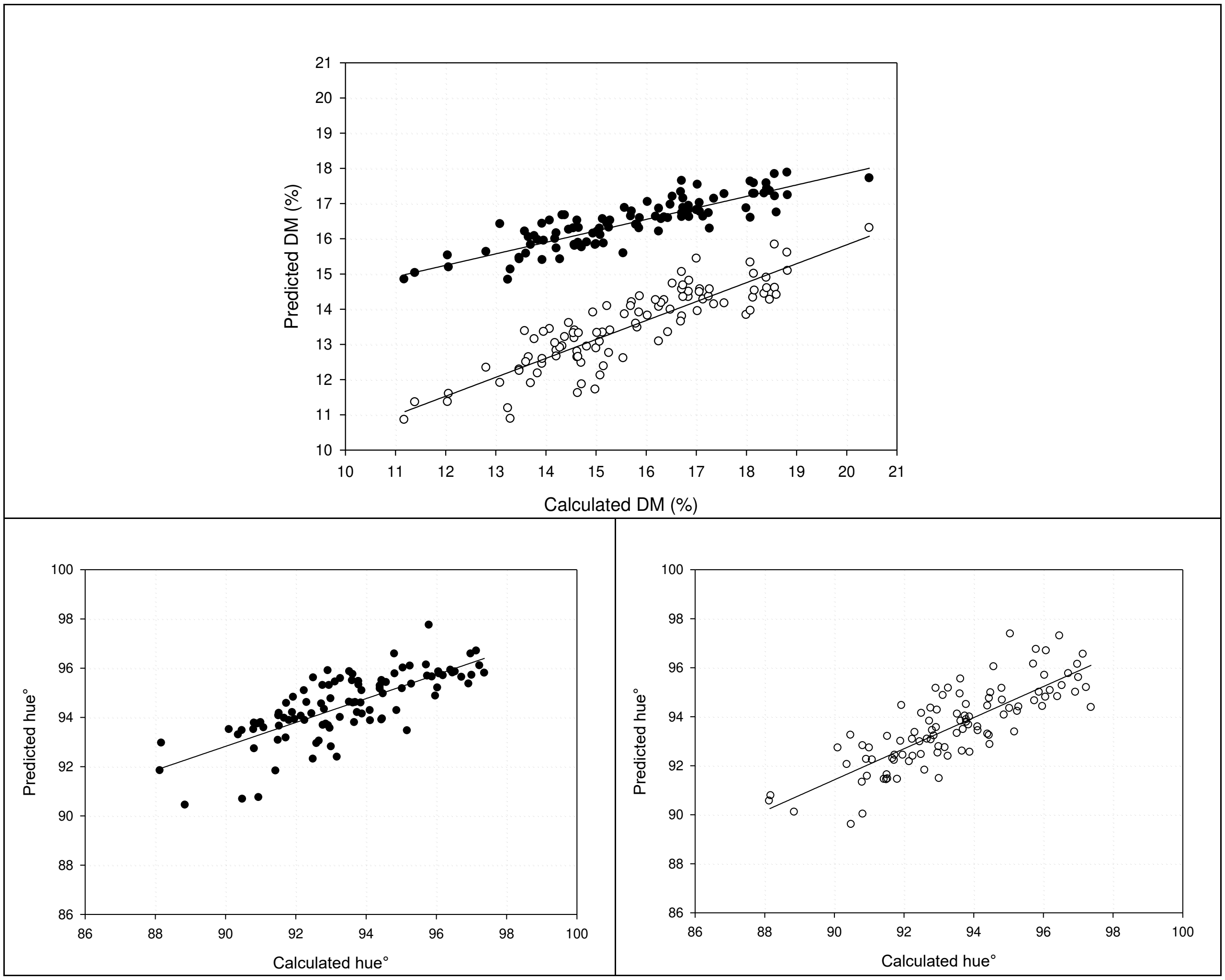

Figure 1. Calculated vs. predicted DM content (%) and hue° for cv. ‘Ataulfo’: T1 (●), R2 (○).

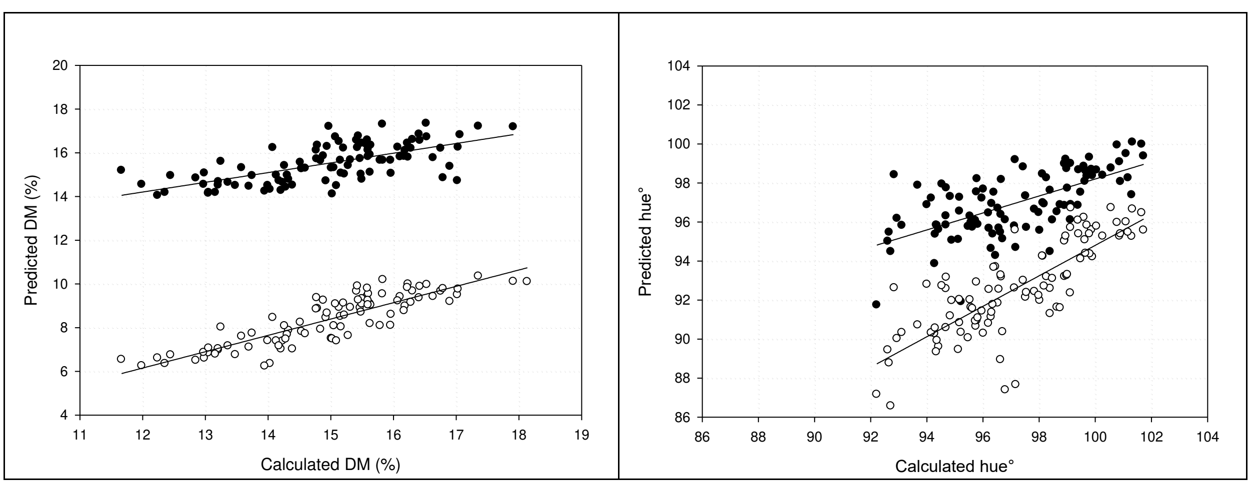

Figure 2. Calculated vs. predicted DM content (%) and hue° for cv. ‘Tommy Atkins’: T1 (●), R2 (○).

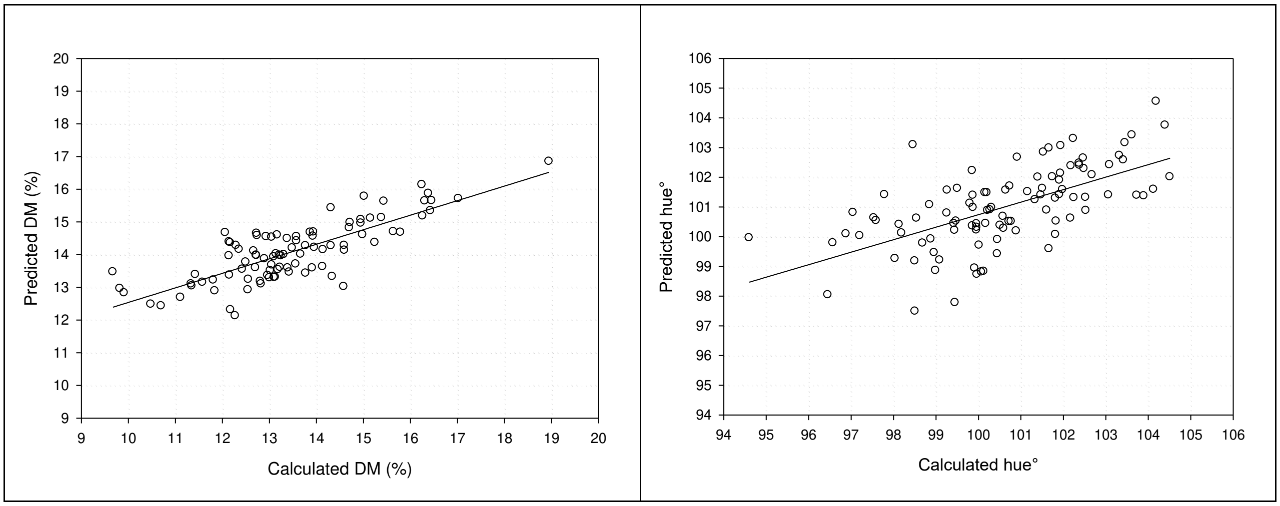

Figure 3. Calculated vs. predicted DM content (%) and hue° for cv. ‘Tommy Atkins’: R2 (○).

3.2. DA-meter instrument

In accordance with previous research works (Infante et al. 2011 and Kader, 1999), the absorbance of the chlorophyll decreases during the last period of fruit development on the tree, due to physiological and horticultural fruit maturation and ripening. Besides, there is a natural variability on ripeness of the fruit within a tree at a given time. Specimens used in this research work were directly bought to a distributor in the receiving point in the US, so it was not possible to know if all of them were harvested from the same tree or orchard or not. It was not possible either to know quality criteria under those they were harvested, so the reliability of DA-meter measurements cannot be confirmed.

Discrimination analyses were carried out establishing categories for DM content and DA-meter values. These analyses were carried out taking into account previous research on peach (Valero, et al., 2007), where DA were developed in order to segregate peaches as a function of non-destructive firmness predictions. Results are showed in following table. The lower limit of class was selected according to a proposed minimum quality index (MQI) based on DM content (Crisosto and Crisosto, 2012). For ‘Tommy Atkins’ and ‘Keitt’ cultivars, no significant differences were observed when DM content was lower than 16%. It would mean that the DA-meter instrument is not capable to segregate fruits which DM content is lower than 16%. However, both cultivars may be segregated into two categories (DM<16%, DM>16%) For ‘Ataulfo’ cultivar, significant differences were observed between DM contents in the range of 14.5 – 17%, and higher than 17%. This result would allow segregating ‘Ataulfo’ mangos into two categories.

Cultivar	DM (%) classes	DA-m	DA-m classes	DM (%)	hue°
Ataulfo	<14.5	1.55 ab	<0.75	15.93 a	92.12 b
	14.5 – 17	1.58 a	0.75 – 1.5	15.70 a	93.80 b
	>17	1.45 b	>1.5	15.47 a	94.97 a
Tommy Atkins	<13	1.52 a	<0.75	15.98 a	96.00 b
	13 – 16	1.39 a	0.75 – 1.5	15.38 b	96.33 b
	>16	1.14 b	>1.5	14.94 c	99.11 a
Keitt	<13	1.99 a	<0.75	15.27 a	96.58 a
	13 – 16	1.91 a	0.75 – 1.5	14.57 a	100.57 a
	>16	1.79 b	>1.5	13.66 ab	99.86 a

Table 3. Discrimination analyses results for three cultivars.

When DA-meter classes were used to segregate specimens into groups, it was observed that, in terms of DM content, no significant differences were observed for ‘Ataulfo’ cultivars. However, ‘Tommy Atkins’ specimens may be segregated in three different groups. Finally, results for ‘Keitt’ cultivar were not clear, although it was possible to state that DA-meter value was inversely proportionate to the DM content.

In terms of flesh color, ‘Ataulfo’ and ‘Tommy Atkins’ cultivars were segregated into two groups. Those with I_{AD} higher and lower than 1.5. However, no significant differences were observed for ‘Keitt’ cultivar.

4. Conclusions

Prediction models built for classification of mango fruits by means of in-line sensors (Compac), as a function of DM content and flesh color showed were significant. ‘Ataulfo’ and ‘Tommy Atkins’ cultivars were segregated as a function of Dry Matter content (%) with 76% of effectivity, while ‘Keitt’ cultivar was segregated with 63%. In terms of flesh color, ‘Ataulfo’ and ‘Tommy Atkins’ cultivars were segregated with 66% and 64% of effectivity respectively. However, segregation of ‘Keitt’ cultivar was not good enough (39%).

To evaluate the reliability of the hand-held instrument (DA-meter), discrimination analyses were carried out establishing categories for DM content and DA-meter values. ‘Tommy Atkins’ and ‘Keitt’ cultivars showed no significant differences were observed when DM content was lower than 16%. It would mean that the DA-meter instrument is not capable to segregate fruits which DM content is lower than 16%. However, both cultivars may be segregated into two categories (DM<16%, DM>16%) For ‘Ataulfo’ cultivar, significant differences were observed between DM contents in the range of 14.5 – 17%, and higher than 17%. This result would allow segregating ‘Ataulfo’ mangos into two categories.

In terms of flesh color, ‘Ataulfo’ and ‘Tommy Atkins’ cultivars were segregated into two groups by using DA-meter. Those with I_{AD} higher and lower than 1.5. However, no significant differences were observed for ‘Keitt’ specimens. At this point, it may be stated that it was observed that these specimens were harvested very green, even immature because they did not ripen properly. According to the National Mango Board recommendations, mangos must be harvested when mature, but not ripe. When mangos are harvested very green or immature, the fruit will not ripen normally.

5. Final comments

In-line segregation of mango fruits in terms of DM content was possible in packing line. However, segregation as a function of flesh color, was possible for ‘Ataulfo’ and ‘Tommy Atkins’, while segregation for ‘Keitt’ was bad. Regarding DA-meter instrument, results showed that it may be possible to use this instrument for segregating specimens into groups of DM content and flesh color, as a function of I_{AD} values.

Additional research works should be carried out in mango orchards in order to establish reliable enough models for segregating fruits by using DA-meter instrument, as a function of flesh color for each genotype and cultivar. Models of flesh color evolution should be developed in the last stage of maturity, in order to understand the behavior of cultivars during this stage and thus, optimize the date of harvesting, being cheaper and more profitable. Finally, mango fruits would be more homogenous from the quality point of view when arrival to the US.

6. References

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