

DOI: <https://doi.org/10.24297/jaa.v12i.9069>**Novel Nondestructive Technique to Determine Optimum Harvesting Stage of 'Ataúlfo' Mango Fruit**Jorge A. Osuna-García<sup>1\*</sup>, Jesús Daniel Olivares-Figueroa<sup>2</sup>, Peter M.A. Toivonen<sup>3</sup>, Ma. Hilda Pérez Barraza<sup>1</sup>, Ricardo Goenaga<sup>4</sup> and María J. Graciano-Cristóbal<sup>1</sup><sup>1</sup> INIFAP-Santiago Ixcuintla Experimental Station. Km. 6 Entronque Carretera Internacional Mexico-Nogales. Santiago Ixcuintla, Nayarit. 63300. Mexico<sup>2</sup> Unidad Académica de Ciencias Básicas e Ingenierías. Universidad Autónoma de Nayarit. Tepic, Nayarit. 63000. Mexico<sup>3</sup> Science and Technology Branch Agriculture and Agri-Food Canada. Highway 97. Box 5000. Summerland B.C. V0H 1Z0<sup>4</sup> USDA-ARS-Tropical Agriculture Research Station. Mayaguez, Puerto Rico 00680\* Correspondence: [josunaga2@hotmail.com](mailto:josunaga2@hotmail.com)**Abstract**

A portable spectrometer was validated to determine optimum harvesting stage of 'Ataúlfo' using dry matter and skin color as fruit indicators. To build the model, samples were collected as follows: a. Unripe; b. Green Mature 1; c. Green Mature 2; d. Green Mature 3; and e. Fully mature. Fruit were scanned with a near infrared spectrometer at three temperatures (15, 25, and 35 °C). Skin color ('a' value) was measured with a Minolta 400 colorimeter. DM was attained in a conventional oven by drying samples for 72 h at 60 °C. Model was built and validated three times. The best model linearity was obtained on skin color 'a' ( $R^2 = 0.98$ ), whereas for DM the  $R^2$  was only 0.70. For the first validation, the best predicted value was skin color 'a' with an  $R^2 = 0.9144$ , followed by DM with an  $R^2 = 0.7056$ . On the second validation, the adjusted predicted value for skin color 'a' had an  $R^2 = 0.8798$ , while DM had an  $R^2 = 0.4445$ . When comparing NIR versus Heat Units Accumulation, in Nayarit, 'Ataúlfo' skin color average difference between the spectrometer vs the colorimeter was only -0.04. For 'Ataúlfo' from Sinaloa, skin color average difference was only -0.06, but the correlation was higher ( $R^2 = 0.90$ ). In conclusion, measuring skin color with the NIR spectrometer has potential as a nondestructive technique to determine the optimum harvesting stage of 'Ataúlfo' mango.

**Key words:** Dry matter; *Mangifera indica*; maturity stage; skin color; spectrometer F-750.**Introduction**

Mango (*Mangifera indica* L.) is a tropical fruit usually harvested in a mature green stage. This translates in fruit not always arriving with the quality and flavor expected by the consumer. The U.S. imports mango from Brazil, Peru, Ecuador, Haiti, Guatemala, and Mexico with an approximate volume of 120 million 4-kg boxes. The main exporter to the U.S. is Mexico with 65.6% of the volume traded, of which, almost 30% belongs to 'Ataúlfo' [1].

Mango maturity stage and quality depend on a large number of attributes, which are measured by various methods along the export chain. Fruit quality traits include firmness, skin color or pulp color, content of total soluble solids, acidity, dry matter content (DM) and aroma, among others [2].

Mango fruit quality fruit at consumption depends mainly on the maturity at harvest. Harvesting discrimination between an immature or mature fruit is extremely important because an immature fruit never reaches its maximum potential quality at the time of consumption. The development of pulp color is a good indicator of fruit maturity, however, DM content has recently been used as a more accurate indicator [3], since it is highly correlated with final total soluble solids (TSS) concentration in fruit ready for consumption. DM content can be determined quickly by means of a microwave oven (4 to 7 minutes)[4]. A minimum quality index (MQI) based on store tests has been developed to determine a minimum DM content at harvest or at arrival point after export. This MQI can be used to predict TSS required in fruit ready for consumption and serves to measure the potential consumer acceptance for mango varieties marketed in the U.S. [5]. Recently, the Australian Mango

Industry Association recommended to harvest Calypso and Kensington Pride varieties when 90% of fruit have a DM of 15% or higher, or a mean of about 16.5% using a calibrated refractometer [6, 7]. 'Ataúlfo' is a Mexican variety with recognition of origin in the Soconusco region of Chiapas [8]. It is one of the most important export varieties accounting for 30% of the total volume exported to the U.S. [9]. Its fruit has a light-green skin at harvest, turning yellow-orange at the fully-mature stage.

This research was conducted to build a Model and validate a portable spectrometer to determine optimum harvesting stage of 'Ataúlfo' mango using DM and skin color as fruit quality indicators.

## Materials and methods

### Building 'Ataúlfo' model

Reference mango samples were collected on 9 May 2018, from an orchard located in 5 de Mayo, San Blas County, Nayarit State, Mexico. Three hundred 'Ataúlfo' fruit were harvested at different maturity stages and 200 selected using five categories of 40 fruit each: a. Unripe, b. Green Mature 1 (GM1), c. Green Mature 2 (GM2), d. Green Mature 3 (GM3), and e. Fully mature (Fig. 1). Fruit were scanned with an F-750 spectrometer (CID Bio Science, Camas, WA) to obtain the spectra at three temperatures (15, 25, and 35 °C). To reach the desired temperature, fruit were maintained for at least four h in a commercial refrigerator (15°C), overnight at room conditions for 25°C, or in a growth chamber at 35°C, respectively. Skin color was also measured at each temperature with a Minolta 400 colorimeter (Minolta Sensing Americas, Ramsey, NJ), to obtain the 'a' value (green to red gradient in the CIELAB color space; [10]). DM was attained in a conventional oven (Binder ED-240, Fulttinger, Germany) drying 10 g of fruit pulp for 72 h at 60 °C [11]. The training set (scanned values) and reference values gathered were loaded into the F-750 model builder software, which identifies correlations between the reference values and 2<sup>nd</sup> derivative absorbance spectra from the training set. This is accomplished using a non-linear iterative partial least square (NIPALS) regression [12]. The model for DM was built in the wavelength range of 801 to 975 nm, while for skin color was in the 501 to 618 nm range. Both models were evaluated based on the adhesion to model linearity.



**Figure 1. 'Ataúlfo' fruit maturity stages for building the model. From left: Unripe, Green mature 1 (GM1), Green mature 2 (GM2), Green mature 3 (GM3) and Mature (colorful).**

### First validation

We selected six different lots of 35 fruit each. 'Ataúlfo' fruit were collected from the packinghouse NATURAMEX, located in 5 de Mayo, San Blas County, Nayarit State, Mexico the same day of harvest (31 May 2018). Fruit were chosen randomly from commercial lots containing 600 field boxes of 20 kg each. Then, they were kept overnight at room temperature ( $\approx 22$  °C;  $80 \pm 5$  % RH). Each fruit was marked on the left cheek side for scanning with the F-750 loaded with the 'Ataúlfo' Model. Skin color was always measured on the same side and DM determined

as described previously. Skin color and DM values predicted with the F-750 were correlated with true values determined by a Minolta 400 colorimeter and oven, respectively.

### Second validation

It was conducted in the same packinghouse in the same way as the first one. We selected six different lots of 35 fruit each. 'Ataúlfo' fruit were selected the same day of harvest (18 June 2018). All procedures were the same as in the first validation.

### Third validation

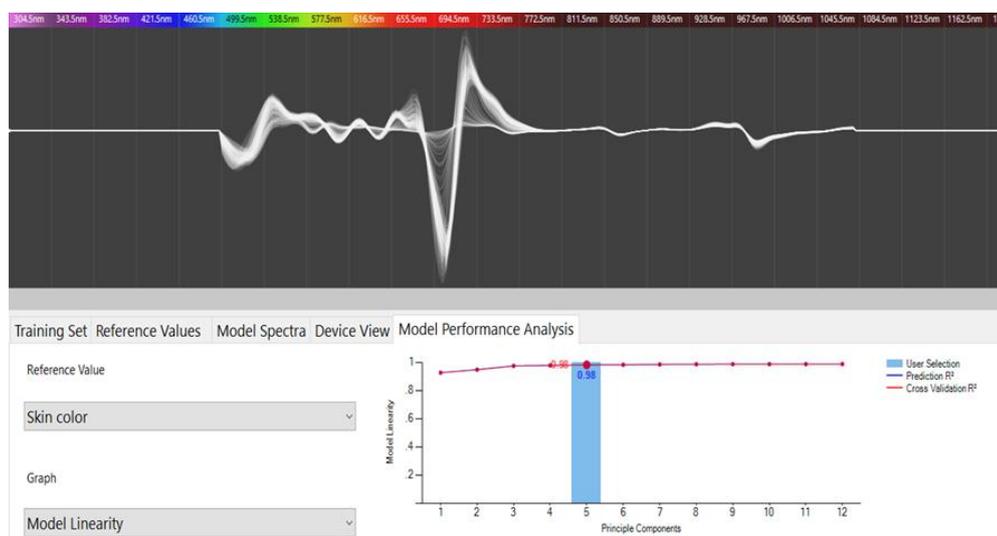
'Ataúlfo' fruit from orchards located in Nayarit and Sinaloa states were selected at harvest day (on 13 June 2018 for Nayarit and on 18 June 2018 for Sinaloa, respectively). Fifty fruit were picked up just when completing 1,600 heat units (HU) according to Osuna et al. [13]. Fruit were shipped the same day of harvest to the postharvest lab and kept overnight at room temperature. Then, fruit were marked on the left side, scanned with the F-750 spectrometer and true values measured with a colorimeter and oven as discussed before. Correlations were done between predicted and observed values.

## Results and discussion

### Building 'Ataúlfo' model

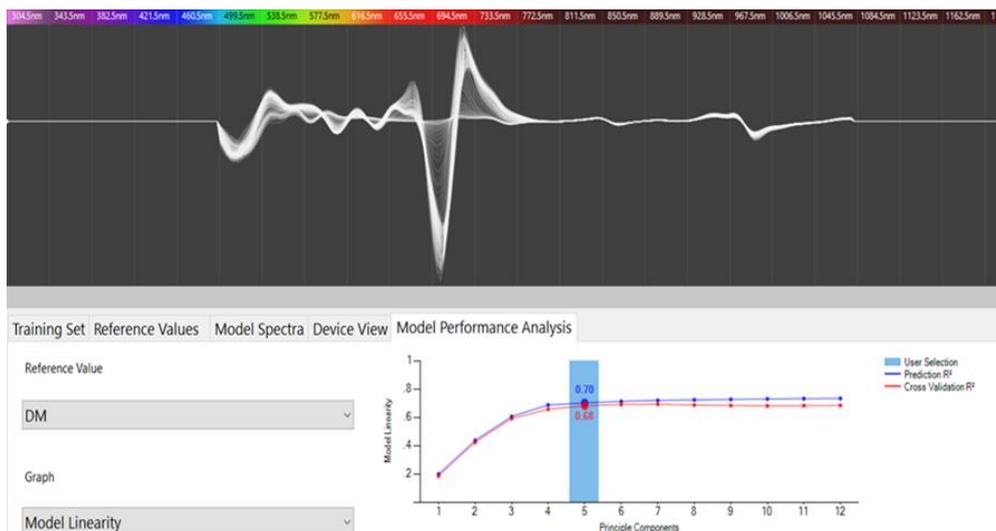
The building of the model and the validation of each parameter (skin color and DM) were carried out to experimentally verify the predictive capacity of the F-750 spectrometer. The correlation coefficient was calculated in each validation to obtain a relationship between predicted results with the F-750 spectrometer and those measured in the laboratory. The estimated linearity with  $R^2$  and the correlation coefficient ( $r$ ) were calculated with training set (scanned values).

Data obtained from fruit measurements were entered into the F750 model builder computer program for building the 'Ataúlfo' mango prediction model. In this program, the performance of the prediction model was analyzed by considering the linearity of each parameter. For skin color an  $R^2$  of 0.98 was obtained (Fig. 2), whereas for DM the  $R^2$  was 0.70 (Fig. 3).



**Figure 2. Performance analysis of the 'Ataúlfo' model achieved with the F750 model builder for skin color**

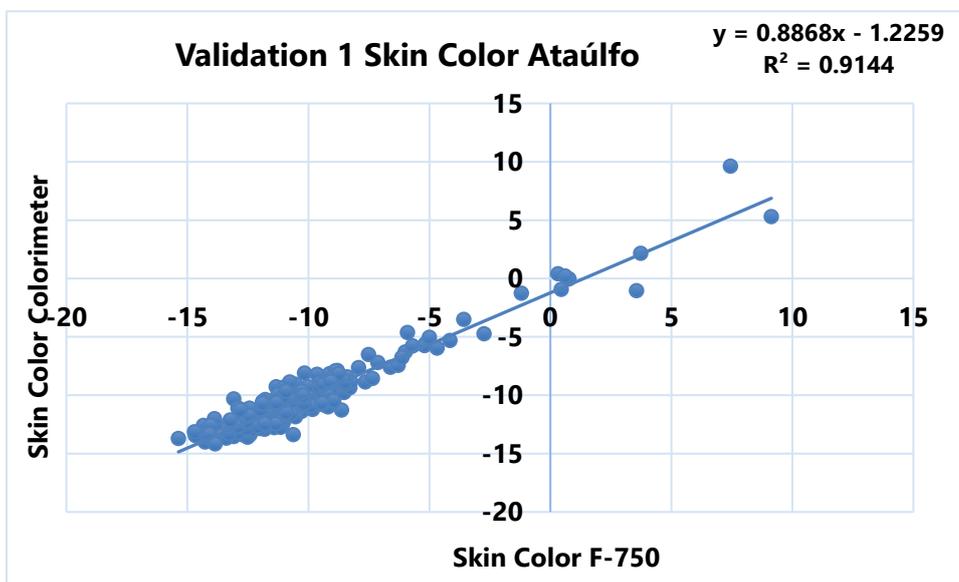
In recent years, near infrared spectroscopy has become a novel non-destructive technique to evaluate the internal and/or external quality of many fruit such as apple [14], mandarin [15], peach [16], apricot [17], and mango [18, 19, 20, 21, 22]. However, there is a scarcity of information concerning NIR analysis for whole mango fruit, specifically 'Ataúlfo' variety.



**Figure 3. Performance analysis of the 'Ataúlfo' model achieved with the F750 model builder for dry matter**

**First and second validation**

Figures 4 and 5 show the linearity obtained for skin color 'a' ( $R^2 = 0.91$ ) and DM ( $R^2 = 0.70$ ). In each figure the predicted value was plotted against the value obtained in the laboratory. The best predicted fit was skin color 'a'. These results were confirmed by a second validation. Fig. 6 and 7 show the linearity achieved for skin color 'a' ( $R^2 = 0.87$ ) and DM ( $R^2 = 0.44$ ).



**Figure 4. Skin color linearity from the first validation of the 'Ataúlfo' model**

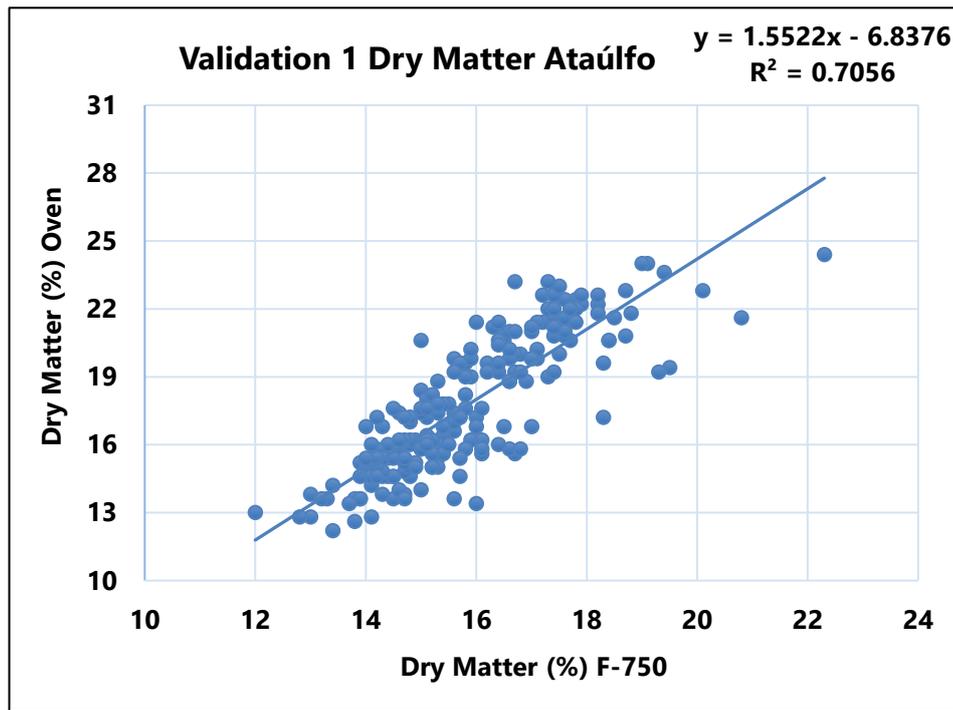


Figure 5. Dry matter linearity from the first validation of the 'Ataúlfo' model

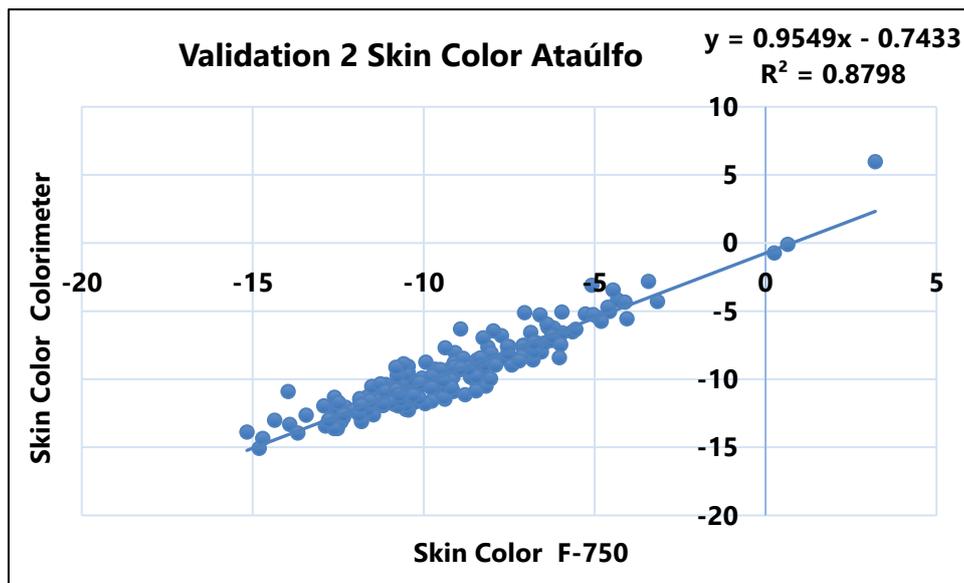
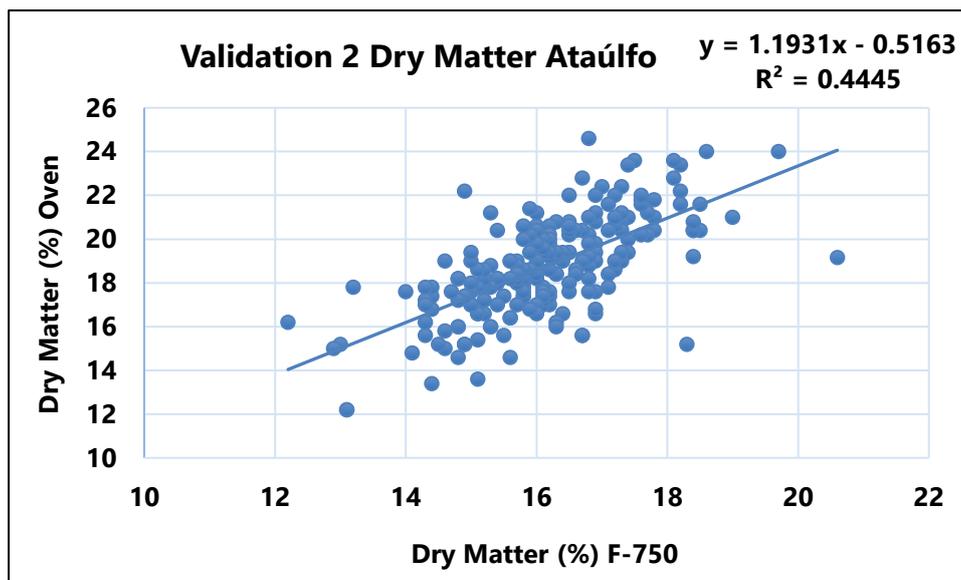


Figure 6. Skin color linearity from the second validation of the 'Ataúlfo' model



**Figure 7. Dry matter linearity from the second validation of the 'Ataúlfo' model**

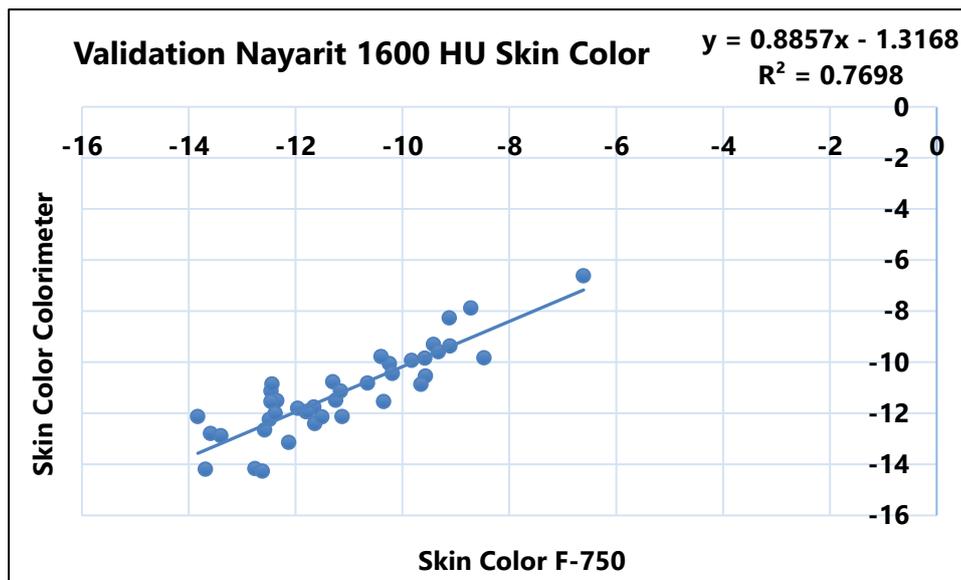
Comparing results obtained in this study with others is difficult due to the differences parameters measured, absorbance range used, spectral measurement procedures, and the handling of outliers. However, there is evidence from other studies which have also found models that serve as a tool for evaluating different quality parameters.

Cocetta et al. [23] used models based on non-destructive evaluations of quality parameters using a portable delta absorbance meter to predict processes during the climacteric maturity phase in 'Red Delicious', 'Golden Delicious', 'Morgenduft' and 'Gala' apples by correlating TSS-concentration, titratable acidity and firmness with absorbance index, during harvest and after cold storage. In that study, TSS in 'Red Delicious' apple, and firmness in 'Golden Delicious' apple. Likewise, Delwiche et al. [24] used NIR to determine TSS concentration in whole 'Ataúlfo' mango harvested in Mexico, obtaining an  $R^2 = 0.88$ .

Walsh et al. [25] indicated that when using NIR, TSS is the most common parameter used to predict maturity in fruit and vegetables, followed by acidity and firmness. The reason why it was decided to evaluate skin color in the present study is because this is a very important quality trait for consumer acceptance, whether aesthetic or linked to proper maturity [26]. On the other hand, recent research has shown the potential use of the NIR to evaluate DM as a maturity index for Australian mango varieties [27]. However, results obtained in this study showed that skin color is a better predictor to assess optimum 'Ataúlfo' maturity rather than DM, which may be correlated to genetically differences between mango varieties.

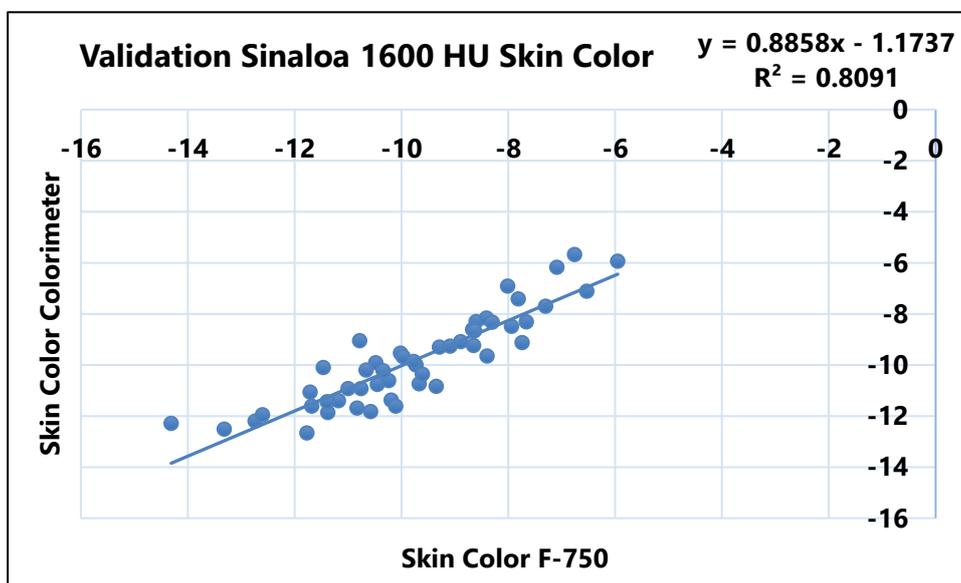
### Third validation

To assess 'Ataúlfo' maturity using the F-750 spectrometer versus the heat accumulation units (HAU) technique [13], results showed that fruit harvested in Nayarit at 1,600 HU, had skin color values ranging from -14.26 (dark green) to -6.61 (light green) with an average of -11.18. Skin color values predicted by the F-750 model versus the Minolta colorimeter was only -0.04. The linearity obtained was  $R^2 = 0.76$  (Fig. 8).



**Figure 8. Comparison of F-750 versus Heat Units Accumulation (HUA) technique for 'Ataúlfo' fruit harvested in Nayarit at 1,600 HU**

For 'Ataúlfo' fruit harvested in Sinaloa at 1,600 HU, skin color values ranged from -12.67 (dark green) to -5.68 (light green) with an average of -9.82. In this case, the skin color average difference between the F-750 versus the Minolta colorimeter was -0.06, but the linearity was slightly higher ( $R^2 = 0.80$ ) [Fig. 9]. Thus, the F-750 spectrometer showed to be a promising tool to determine optimum harvest stage of 'Ataúlfo' mango fruit based on skin color.



**Figure 9. Comparison of F-750 versus Heat Units Accumulation (HUA) technique for 'Ataúlfo' fruit harvested in Sinaloa at 1,600 HU.**

In conclusion, on the basis of the predictive model developed for skin color in this study, the F-750 spectrometer can be considered a promising tool to determine the optimal harvest stage for 'Ataúlfo' mango. This model for 'Ataúlfo' cannot be considered as a harvest index tool for other cultivars having different skin color tones, but may be useful for Manila and Alphonso like cultivars.

### Data Availability

Any of this data can be obtained from the corresponding author at [josunaga2@hotmail.com](mailto:josunaga2@hotmail.com)

### Conflicts of interest

There are no conflicts of interest.

### Funding Statement

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