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DETERMINATION OF COLOR AND FRUIT TRAITS OF HALF-SIB FAMILIES OF MANGO (*MANGIFERA INDICA* L.)

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Abstract. **The visual appearance of fresh fruits and vegetables is one of the first quality determinants made by the consumer. Often the appearance of the commodity is the most critical factor in the initial sale. In Florida, the color of the mango (*Mangifera indica* L.) is an important factor and everyone admires a handsome mango that is generously overlaid with red. Red skin is considered a necessity for mangos shipped to northern markets, even though other aspects of quality may be inferior to that of non-showy cultivars. In the past, the evaluation of mango color has been subjective and based on visual ratings. Large errors are associated with these types of ratings, which makes evaluation of the varieties based on fruit color difficult. The present paper illustrates the use of a colorimeter to quantify fruit color, quality, and differentiation among varieties. Mango color was measured with a Minolta Chroma Meter CR-400 portable tristimulus colorimeter and fruit chromaticity was recorded in Commission Internationale d'Eclairage *L**, *a** and *b** color space coordinates. In this system of color representation the values *L**, *a**, and *b** describe a uniform three-dimensional color space, where the *L** value corresponds to a dark-bright scale, *a** is negative for green, and positive for red, and *b** is negative for blue and positive for yellow. For each sample, color values were measured at the base, cavity, and apex on each mango. Detailed data was obtained from six half-sib families and two clonal checks in 2004. Fruit and seed size and weight, fruit number, % Brix, jelly seed, and anthracnose resistance were also evaluated. The ability to quantify color readings could allow us to estimate the heritability of this trait and aid in the selection of parents to use in breeding new cultivars.**

Mango, *Mangifera indica* L., a member of the family Anacardiaceae, is native to southern Asia and one of the most popular tropical fruits. Mango is a popular dooryard fruit tree in Florida, Hawaii, Puerto Rico, and Guam and is available as fresh fruit year around in North America, Japan and Europe (Morton, 1987). Mango is a minor crop in the United States with 650 ha currently under cultivation in Florida and 870 ha in Puerto Rico (FAOSTAT, 2004). There are hundreds of mango cultivars (i.e., 'Kent', 'Haden', 'Keitt', 'Alphonso', 'Manila', 'Ah Ping', 'Fairchild', 'Gouveia', 'Harders', 'Keitt', 'Momi K', 'Pope', 'Julie', and 'Rapoza'), among which 'Tommy Atkins' is one of the most popular cultivars in North America. The external color of mango fruits produced is an important factor in consumer appeal (Campbell and Campbell, 2002; Litz and Lavi, 1997). With adequate disease control (anthracnose, black mold rot), color development of most yellow cultivars is no problem. However, color development of some red cultivars (i.e., 'Tommy Atkins') can be extremely variable.

Mango producers are constantly in need of improved cultivars that satisfy the requirement and preferences of consumers. This has stimulated a search for new cultivars with better quality and greater genetic diversity which are adapted to the environmental conditions of Florida and other areas worldwide. It appears that the average consumer chooses fruits and vegetables according to their external appearance, while their nutritional value and cost are of secondary interest (Shewfelt, 1990). Besides size, firmness and taste, one of the most important factors determining acceptance of fruits and vegetables is color (Riquelme, 1995). This could be true in the case of mango, where color and perhaps firmness may determine the consumer selection.

Presently, color cards have been used for classification of fruits, flowers, and vegetables on the basis of their external color. However, in addition to depending on subjective interpretation, they do not facilitate the visual separation of varieties (Kavanagh et al., 1986). To overcome this dilemma, color reflection techniques values have been developed which provide tristimulus values, from which the chromatic coordinates on the CIELAB color system can be acquired (McGuire, 1992).

The colorimeter generates a composite, three parameter L*a*b* number. The CIE 1976 L*a*b* color space is the most widely used method for measuring and ordering object color. Manufacturers of textiles, inks, paints, plastics, paper, printed materials, and other objects routinely employ it throughout the world. It is sometimes referred to as the CIELAB color difference metric. In the CIE L*a*b* uniform color space, the color coordinates are: L*—the lightness coordinate; a*—the red/green coordinate, with +a* indicating red, and -a* indicating green; and b*—the yellow/blue coordinate, with +b* indicating yellow, and -b* indicating blue. The L*, a*, and b* coordinate axis defines the three dimensional CIE color space. Thus, if the L*, a*, and b* coordinates are known, then the color is not only described, but also located in a quadrant.

The ability to quantify formerly qualitatively evaluated fruit parameters should be of interest to breeders and growers. Once obtained, this information could be used to assist in cultivar development programs. Several mango cultivars have been collected and are being evaluated in field experiments at the Subtropical Horticulture Research Station (SHRS) Miami, FL (Schnell and Knight, 1998). The objective of this study was to characterize fruit traits of several mango half-sibs, and examine the potential use of a colorimeter to characterize mango color.

Material and Methods

Maternal half-sib families (MHS) of the mango cultivars, 'Keitt', 'Tommy Atkins', 'Tyler Premier', 'Mamita', 'White Alfonso', and 'Sandersha' (Fig. 1) were evaluated in a field experiment established at the SHRS in June 1996. Two parental

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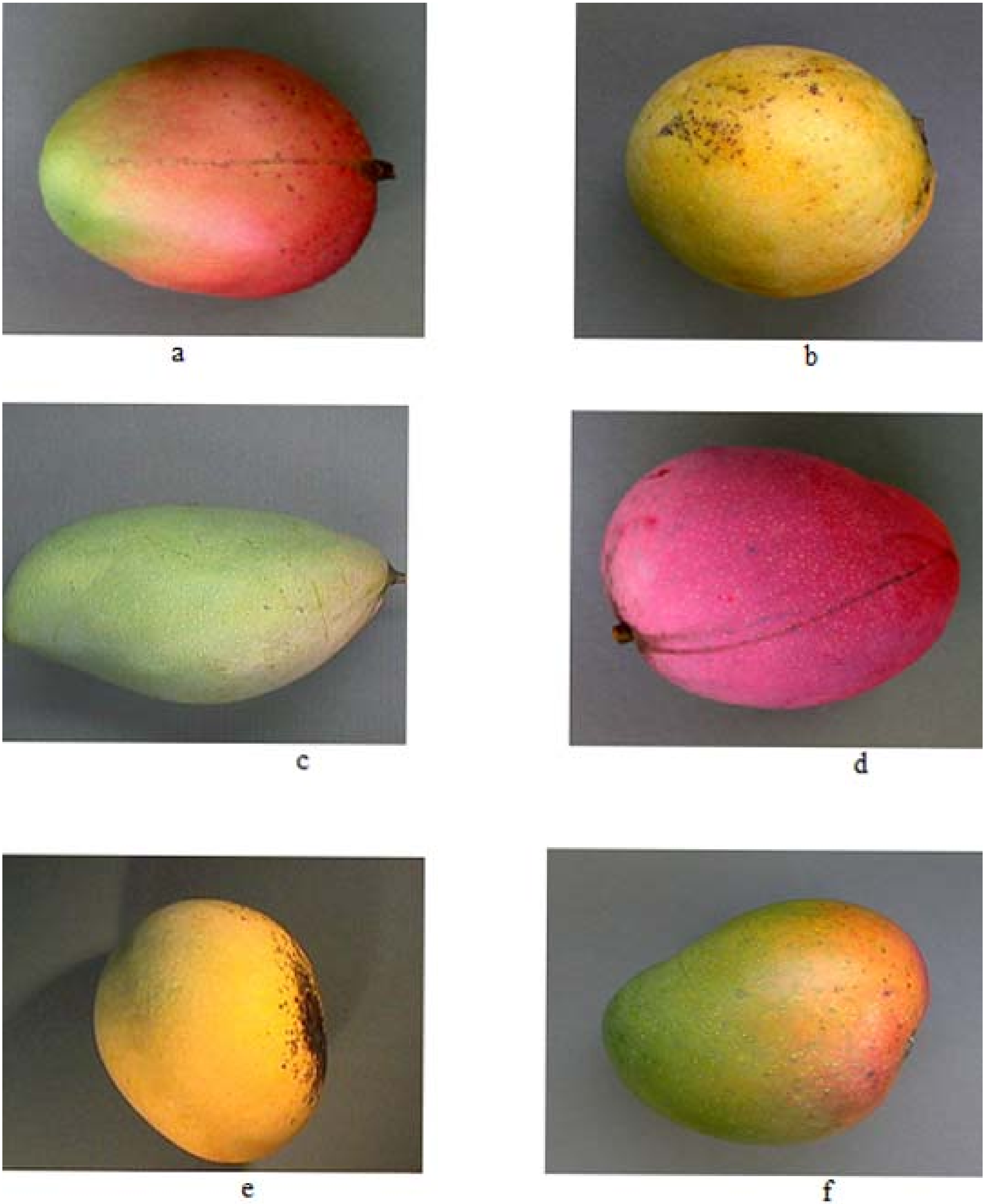

Fig. 1. Digital images of selected cultivars. 'Keitt' (a); 'Mamita' (b); 'Sandersha' (c); 'Tommy Atkins' (d); 'Tyler Premier' (e); and 'White Alfonso' (f).

check clones of 'Tommy Atkins' and 'Keitt' were also included. The maternal half-sib families consisted of open pollinated seedlings, while the check clones ('Keitt' and 'Tommy Atkins') were grafted on 'Turpertine' rootstock. The parental clones were chosen on the basis of being recognized as commercial types. The experimental design was a randomized complete block design, with three replications. Each experimental plot consisted of 10 trees per plot. Fertilization and cultural practices were as recommended for mango production under south Florida production (Ruehle and Ledin, 1956).

Data Collection Procedures. Data for evaluation were collected in 2004. Plants were harvested several times from 2 June until 25 July 2004. Although the experimental plots consisted of ten trees, fruits were generally collected from one or two trees per plot, as they were the only producing trees that year. The traits measured included total number of fruit produced; fruit weight, length, and width; skin and flesh color; seed weight; Brix; internal breakdown (jelly seed); and tolerance to anthracnose.

Fruit weight was measured on a digital scale (grams) and recorded. Fruit length and width were measured (mm) with a ruler mounted on plexi-glass fixed slide rule and recorded. Soluble solids were determined using a portable handheld refractometer model 300002 (Sper Scientific, Ltd., Scottsdale, Ariz.). The value was recorded for each individual fruit and expressed in °Brix. Jelly seed and anthracnose tolerance was based on a 1-5 rating (1 severe and 5 not present).

Skin Color Measurement. Color measurements of mangoes were made using a portable CR-400 tristimulus colorimeter (Minolta Chroma Meter CR 400, Osaka, Japan) and SpectraMatch software, set to L*, a*, b* mode. The colorimeter has a beam diameter of 8 mm, three response detectors set at 0 viewing angle and a CIE standard illuminant C with diffuse illumination (Fig. 2). This illuminant is accepted as having a spectral radiant power distribution closest to reflected diffuse daylight.

Color changes were documented over the duration of the experiment. L* values indicate lightness (black [L* = 0] and white [L* = 100]), a* values indicate redness-greenness (red [a* = 100] and green [a*= {-100}]), b* values indicate yellowness-blueness (yellow [b* = 100] and blue [b* = {-100}]). Chroma (*C*) (*C* = [(a*)2 + (b*)2]0.5) measures color saturation or intensity and the hue angle (*h* = arc tan b*/a*) determines the red, yellow, green, blue, purple, or intermediate colors between adjacent pairs of these basic colors. A lower hue value indicates a redder product. The L*, a*, and b*, *C* and *h* values obtained from each mango at the time of sampling represent average L*, a*, and b*, *C* and *h* values calculated from three separate light pulses from the colorimeter. A white plate was used for calibration (L* = 98.15, *C** = 1.92, *h*°* = 93.8, a* = 0.13, b* = 1.92). Each sample was placed on a white table, and L*a*b*C*h°* and CIELAB color measurements were taken in triplicate. The light pulses were timed to allow movement of the colorimeter to 3 locations on each mango. Every record represents the average of three readings which were taken, at the base, the cavity, and the apex, spaced equidistantly. Thus, using this method allowed for the 'true', overall color of each mango to be assessed, regardless of small patches of tissue discoloration.

Statistical Analysis. Descriptive analysis and test of normality were performed on data to verify ANOVA assumptions. The overall F-test to detect differences among half-sib families and checks were made using the Satterthwaite approximation of the denominator degrees of freedom (Fai and Cornelius, 1996). Least square means were calculated and multiple comparisons were performed adjusting the p-value with the Tukey-Kramer method (Kramer, 1956). Descriptive analysis and statistical models (ANOVA and mean separation) were performed using the UNIVARIATE and MIXED procedures of PC-SAS version 9.1 (SAS Institute, Cary, N.C.), respectively.

Fig. 2. Chromameter CR400.

Results and Discussion

Highly significant differences ($\alpha = 0.01$) were found for all traits evaluated according to the F test (Tables 1 and 2). Tables 3 and 4 show the least square means comparison for the color measurements and biophysical traits evaluated in the six mango half-sibs and two check cultivars used in the experiment.

Color Analysis. The *L** mean values range from 48.6 to 65.8; *a** mean values ranged from 1.3 green color to 22.8 red color. Whereas *b** mean values ranged from 2.31 to 3.60 (Table 3). The multiple comparison of the least squares mean showed few significant differences for the color variables *L** *a** *b**, *C* and *h* (Table 3). This is due to large standard error of the estimator, attributed mainly to the fact that each observation represents the average of readings of three sections of the fruit, rather than only one section at a time. Data collection is currently being done for each fruit section from fruits produced this year. At this point, we present a discussion on the results of the combined measurements.

Half-sibs of the cultivars, 'Sandersha' and 'Mamita', had the greater luminosity (highest *L** values) in the fresh fruits (Table 3). 'Sandersha' half-sibs were the most luminous (*L** = 65.8), while 'Tommy Atkins' was the least luminous (*L** = 48.6). These *L** values could be correlated with the total pigment (color) of these families. This is in agreement with the lower luminosity value observed in the clone 'Tommy Atkins' which is distinguished by a dense red color. Half-sibs of 'Sandersha' showed a significant difference in *L** value from all other cultivars. This cultivar is characterized by a greenish color therefore inducing a higher luminosity than the other cultivars.

Table 1. F-statistic (F_c) and significance of fixed effects of color variables corresponding to mango cultivars evaluated in a field trial at USDA-ARS, SHRS, Miami, Fla.

		Trait									
		L*		a*		b*§		C*§		h°§	
Source	df_N†	df_D‡	F_c	df_D	F_c	df_D	F_c	df_D	F_c	df_D	F_c
Cultivar	7	10.50	6.83**	11.3	46.89**	8.9	13.00**	8.9**	26.18**	11.80	82.40**
Replication	2	7.79	0.39	8.2	0.20	6.5	0.42	6.7	0.51	8.16	0.06

*,**Indicates significance at P = 0.05 and 0.01.
†Numerator or degrees of freedom.
‡Satterthwaite approximation of denominator degrees of freedom (Fai and Cornelious, 1996).
§Variable transformed as the natural logarithm of the original units.

The *a** or red-green values in the eight cultivars studied showed significant differences between half-sib families (Table 3). The cultivar 'Tommy Atkins' clonal (C) showed the greatest red color (*a** = 22.8), followed by 'Keitt' half sib (HS) and 'Tommy Atkins' (HS), respectively. This is in accordance with the typical red color of the 'Tommy Atkins' cultivar.

The *b** or yellow-blue component (all values positive) values were the highest for the half-sib families of 'Sandersha', 'White Alfonso', and 'Mamita', whereas the lowest values were shown by 'Tommy Atkins' clonal (C) and both 'Keitt' clonal (C) and half-sibs. These results agree with the color of the cultivars, 'Sandersha', 'White Alfonso', and 'Mamita', characterized by intense yellow shades.

The Chroma (*C*) value measures color saturation or intensity. A higher *C* value is indicative of a brighter red color. The half-sibs of 'Sandersha' and 'Tommy Atkins' (HS) showed the highest *C* value (Table 3) among groups, whereas the cultivar 'Keitt' (C) showed the lowest *C* value (2.89). A high bright red color of some tomato cultivars have been associated with a strong positive influence in the market place (Gomez et al., 1998), whereas a light (low) red color have been associated with a negative response by consumers.

The hue angle (*h*), that correlates with the *and *b** values, was a good factor to assess changes of the characteristic color in these cultivars. Lower *h* values indicate a redder color, as exemplified by the cultivar 'Tommy Atkins' clonal (*h* = 3.11). 'Tommy Atkins' (C) showed a significantly different *h* value from all cultivars (Table 3). The red color of the other cultivars was masked by an increase in yellow.

Fruit and Seed Weight. A significantly higher fruit weight (84.7 g) was recorded for 'Keitt' (C) and the lowest fruit weight was observed for 'White Alfonso' (Table 4). Clones showed significant differences from their progeny with respect to fruit weight. 'Keitt' (C) showed a higher significant increase in fruit weight compared to 'Keitt' (HS). 'Tommy Atkins' (C) showed a significant decrease in fruit weight (Table 4) compared to 'Tommy Atkins' (HS). The highest seed weight (6.7 g) was recorded for 'Sandersha' (HS) while the lowest seed weight (1.1 g) was showed by White Alfonso (HS). There were no significant differences for the other cultivars or families.

Fruit Length and Width. There were highly significant differences in fruit length among families and clones (Table 4). 'Sandersha' had the largest fruit length (142.0 mm) together with 'Tommy Atkins' (HS) (136.8 mm) and 'Keitt' (C) (122.2 mm), respectively. The lowest fruit length were 'Tommy Atkins' (C) (87.3) and 'White Alfonso' (HS) (81.6 mm), respectively. There were also significant differences in fruit width among clones and half-sib families (Table 4), which followed the similar patterns as for fruit length.

Soluble Solids (Brix). The maximum soluble solids concentration, which basically reflects glucose and fructose content, was observed in 'White Alfonso' (HS) (18.3) and 'Mamita' (HS) (16.6). The lowest Brix content was found in 'Keitt' (C) (Table 4). There were no significant differences among other clones and families.

Internal Breakdown and Anthracnose Resistance. 'Mamita' (HS) and 'Tyler Premiere' (HS) had the lowest tolerance to internal breakdown and anthracnose resistance (Table 4). 'Keitt' (C) and 'Tommy Atkins' (C) had the highest tolerance to internal breakdown and anthracnose resistance.

The present work describes the fruit traits of several mango cultivars and illustrates the potential use of the colorimeter to quantify color characteristics of mango. The colorimeter method makes it possible to access, in situ and in real time, several parameters relating to mango quality. The use of a col-

Table 2. F-statistic (F_c) and significance of fixed effects of fruits traits corresponding to mango cultivars evaluated in a field trial at, USDA-ARS, SHRS Miami, Fla.

		Trait													
		Fruit Weight		Seed Weight		Fruit length		Fruit width		Brix		Int. breakdown		Anthracnose res.§	
Source	df_N†	df_D‡	F_c	df_D	F_c	df_D	F_c	df_D	F_c	df_D	F_c	df_D	F_c	df_D	F_c
Cultivar	7	80.8	66.90**	76.9	54.2**	76.6	47.70**	81.5	68.80**	35.1	8.42**	77.4	1586.7**	76.8	379.00**
Replication	2	13.9	0.05	12.7	1.0	13.1	0.05	13.7	0.16	12.7	0.11	14.0	3.9*	14.0	0.86

*,**Indicates significance at P = 0.05 and 0.01.
†Numerator or degrees of freedom.
‡Satterthwaite approximation of denominator degrees of freedom (Fai and Cornelious, 1996).
§Variable transformed as the natural logarithm of the original units.

Table 3. Least squares means of mango color variables of cultivars evaluated in a field trial at USDA-ARS, SHRS, Miami, Fla.

Cultivar	Type	Trait				
		L*	a*	b*†	C*†	h˚†
a) Keitt	Clonal	55.1 dcgfha	1.3 bcdgh	2.86 abcdfgh	2.89 abdfh	4.46 a
b) Keitt	Half-sib	49.9 dcgfhab	18.1 be	2.94 bcdfgh	3.31 bcdfgh	3.78 abcdfgh
c) Mamita	Half-sib	60.4 dc	7.7 bcdfg	3.46 cdh	3.52 cdf	4.32 acdh
d) Sandersha	Half-sib	65.8 d	8.7 bdefg	3.60 d	3.63 d	4.35 adh
e) Tommy Atkins	Clonal	48.6 dcgfhb	22.8 e	2.31 be	3.26 bcdefgh	3.11 e
f) Tommy Atkins	Half-sib	59.1 dcgf	16.5 bef	3.36 cdfgh	3.56 df	4.06 acdfgh
g) Tyler Premier	Half-sib	60.3 dcg	11.0 bfg	3.37 cdgh	3.46 cdfgh	4.22 acdgh
h) White Alfonso	Half-sib	58.5 dcgfh	5.0 bcdfgh	3.47 dh	3.50 cdfh	4.40 ah

Within columns, means followed by the same letter are not significantly different at the 0.05 provability level. The letters correspond to the cultivar id presented in the first column. Multiple comparison was adjusted for the p-value using the Tukey-Kramer method (Kramer, 1956).
†Variable transformed as the natural logarithm of the original units.

Table 4. Least squares means of fruits traits of mango cultivars evaluated in a field trial at USDA-ARS, SHRS, Miami, FL.

Cultivar	Type	Trait						
		Fruit weight (g)	Seed weight (g)	Fruit length (mm)	Fruit width (mm)	Brix	Int. breakdown	Anthracnose res.†
a) Keitt	Clonal	84.7 a	4.6 ad	122.2 adf	114.4 a	8.8 abe	4.13 ae	1.35 a
b) Keitt	Half-sib	33.2 egb	3.8 abcfg	104.6 abcdf	80.7 bdefg	15.8 bch	3.00 abdefh	1.20 abef
c) Mamita	Half-sib	25.9 ebc	3.9 acf	112.6 ac	69.6 bc	16.6 ch	0.30 bc	0.87 bcd
d) Sandersha	Half-sib	63.4 ad	6.7 d	142.0 d	94.2 df	15.3 bcdh	3.09 d	0.91 bd
e) Tommy Atkins	Clonal	39.4 e	3.6 abcefg	87.3 beg	91.1 def	15.1 bcdeg	4.13 e	1.61 e
f) Tommy Atkins	Half-sib	63.0 df	4.0 af	136.8 df	95.8 f	14.4 bcdefg	4.11 aefh	1.59 ef
g) Tyler Premier	Half-sib	36.3 eg	3.9 acfg	100.1 abg	88.8 defg	15.1 bcdg	2.12 bg	0.90 bdg
h) White Alfonso	Half-sib	14.7 bh	1.1 bh	81.6 be	68.9 bc	18.3 h	4.12 aeh	1.17 bh

Within columns, means followed by the same letter are not significantly different at the 0.05 probability level. Letters correspond to the cultivar id presented in the first column. A multiple comparison was adjusted for the p-value using the Tukey-Kramer method (Kramer, 1956).
†Variable transformed as the natural logarithm of the original units.

orimeter is a promising method for following color changes during fruit ripening and distinguishing among cultivars. Further research is necessary to determine if heritability of color phenotypes can be estimated using the colorimeter readings. Our preliminary data suggests that the use of the colorimeter could help in the selection of mango cultivars.

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