Research Note

MORPHOLOGICAL AND PHENOLOGICAL EVALUATION OF TEN AVOCADO CULTIVARS[1]

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Avocado *(Persea americana)* belongs to the family Lauraceae. It is native to the tropical and subtropical regions of North and South America and has spread to all tropical countries in the world (Schaffer et al., 2013; Ayala-Silva and Ledesma, 2014). The avocado originated in Central America and southern Mexico. Based on archaeological evidence found in Tehuacan, Puebla (Mexico), it is believed to have appeared approximately 12,000 years ago (Yahia, 2011). The avocado tree is an evergreen that attains heights of 20 m, has many branches and produces edible fruits.

Avocado cultivars are classified in three groups or races, known as the West Indian, Guatemalan and Mexican "races". Cultivars fall into one of two pollination types, referred to as type A and type B, the difference being the time of day (morning vs. afternoon) that the male and female flowers are capable of reproduction. Flowers of type A cultivars open in the morning as receptive females, then close in the afternoon until the following afternoon when they reopen for pollen shed. Type B avocado flowers open in the afternoon as receptive females, close overnight and reopen the following morning to shed pollen (Schaffer et al., 2013).

West Indian avocados originated in the tropical lowland areas of southern Mexico and Central America whereas Guatemalan and Mexican avocados originated in mid-altitude highlands in Guatemala and Mexico (Figure 1) (Ayala-Silva and Ledesma, 2014). The fruit of avocado is referred to as a berry, consisting of a single carpel and a single seed (Schaffer et al., 2013). The fruit may be round, pear shaped or oblong, and the skin of the fruit may vary in texture and color. The skin of the fruit may be flexible to woody, smooth to rough, and green-yellow, reddish-purple, purple, or black in color. The flesh of the fruit is greenish yellow to bright yellow and buttery when ripe in good varieties, but in poorer cultivars may be fibrous. The avocado fruit has one large seed that makes up to 10 to 25 percent of the fruit weight. Avocado fruits range from 150 g to more than 1.50 kg in weight.

Choice of cultivars must include many factors to determine the best available for commercial or home use. Soil type and location are quite variable and depend on the characteristics of rootstocks and disease resistance. Cultivars should be selected based on production and resistance to ailments (Knight, 1999) and climatic conditions; rootstocks (Ben-Ya'acov et al., 1992); and consumer requirements, such as minimum or maximum oil content and vitamins according to amended dry weight procedures (OECD, 2004). Further characteristics are size, color, peel roughness and shape, depending on

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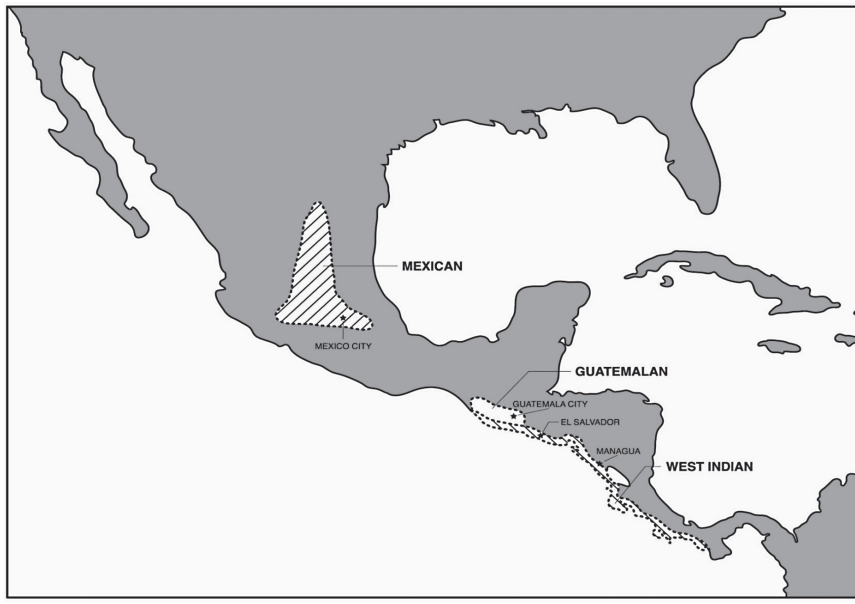

FIGURE 1. Avocado races' origin and distribution (Ayala-Silva and Ledesma, 2014).

consumer taste (Lewis et al., 1979), pulp content (Rouse and Knight, 1991) and ease of skin removal. Supplementary features could be considered when production is oriented to high pulp yield for consumption (Rouse and Knight, 1991) or for the total production of oil (Swisher, 1988).

The objective of this work was to provide agronomic and physiological information on 10 cultivars of avocado to help breeders and consumers choose cultivars based on their health (i.e., diet, high cholesterol) and to complement the agronomic data available, making information accessible in databases that would be useful to growers, consumers and researchers.

Plant materials. During the 2010-2012 avocado seasons, fifty mature fruits of each of the following avocado cultivars from trees at least 15 years old were harvested: 'Aycock Red #3' (Figure 2a), 'Belize', 'Butler' (Figure 2b), 'Donaldson','Ereguayquin #7', 'Jose Antonio' (Figure 2c), 'Lima Late' (Figure 2d), 'Marcus' (Figure 2e), 'Orizaba 3' and 'Tensen' (Figure 2f). The samples were collected from the avocado collection maintained at the National Germplasm Repository (NGR-SHRS) in Miami, Florida, whose location and characteristics have been indicated previously (Ayala-Silva et al., 2005; Ayala-Silva et al., 2013; Gordon et al., 2013). The samples were harvested and then taken to the laboratory and kept at room temperature settings until ripe. Fruits were considered ripe when the skin could be broken with a 0.8 cm width cylindrical plunger in an Instron Universal Testing Machine model 1101[6]. Ten fruits of each cultivar were measured to obtain fruit

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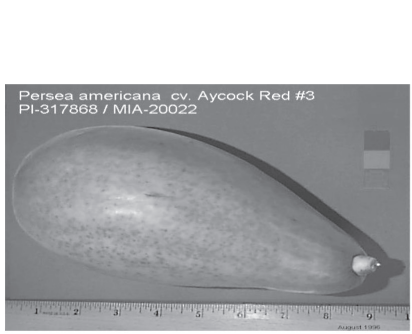


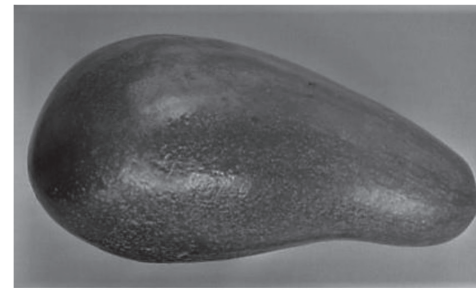
(a) 'Aycock Red #3'

(b) 'Butler'

(c) 'Jose Antonio'

(d) 'Lima Late'

(e) 'Marcus'



(f) 'Tensen'

FIGURE 2. Avocado cultivars

size, weight, color and pulp and seed yield. Ripe fruits of each cultivar were randomly selected, and analytical measurements were performed.

Analysis. A digital scale (Ohaus® Model GT8000; Florham Park, NJ) was used to measure fruit weight (whole fruit, seed and pulp). Fruit length, shape and peel characteristics including roughness, hand peeling, and color were determined. Race and flower type [A or B (Figure 3)] of the selected avocado cultivars are reported.

Color results are the average of three readings taken equidistantly at the top, middle and bottom of the fruit with a CR-400 tristimulus colorimeter (Minolta Chroma Meter CR 400, Osaka, Japan) and SpectraMatch software, set to L*, a*, b* mode using the Lab

Type A flower Type B flower

FIGURE 3. Avocado flower.

Hunter System as described earlier by Ayala-Silva and Meerow (2006); Ayala Silva et al. (2013); Gordon et al. (2013); and Ayala-Silva et al. (2016). Calibration was conducted using a white plate and these calibration factors (L*= 98.15, C*= 1.92, h°*= 93.8, a*=−0.13, b*= 1.92).

The L*, a* and b* values obtained from each avocado fruit at the time of selection symbolize average L*, a* and b* values calculated from three distinct light beats from the colorimeter. Data was analyzed using statistical models (ANOVA and mean separation) using the Univariate procedures of PC-SAS version 9.1 (SAS Institute, Cary, N.C.).

Information on West Indian cultivars and their crosses is lacking. Thus, this may be the first time that most of these cultivars are reported in detail. Comparing data on fruit characteristics from different environments is very difficult since different factors can induce variability even in the same location and at different harvesting seasons (Salazar et al., 1971).

Most cultivars flowered from early January to May and were divided into early, middle, and late flowering groups. The flowering period of 'Lima Late' was the shortest (January to March) followed by 'Orizaba 3' and 'Marcus', which began in early January and ended in late March. While 'Aycock Red' and 'Ereguayquin #7' bloom from early January to early April. 'Lima Late' and 'Donaldson', which belong to the middle flowering group, bloom from late January to late April. The flowering period of the late flowering cultivars, which include 'Butler' and 'Jose Antonio', is from late February to mid-May. The full bloom period of the cultivars fluctuated between seven weeks and five months. Based on the flowering pattern and IPGR (1995) guidance, four cultivars revealed an A flower type, and six presented a B flower type (Table 1).

Fruit size and shape impact market value and are important physical attributes in sorting, sizing, packaging and transporting fruits (Storey et al., 1973). Seed size is very important in any fruit for consumption. Consumers prefer fruits with a small seed and large pulp content (Ayala-Silva et al., 2005).

'Jose Antonio', 'Lima Late', 'Marcus' and 'Tensen' demonstrated the highest weight, while 'Belize', 'Orizaba 3', and 'Donaldson' showed the lower weight (Table 2). Further, 'Jose Antonio' and 'Lima Late' were the cultivars with the highest pulp proportion ($p < 0.05$) in this group (Table 2); however, there was a significant difference in seed weight (Table 2) between these two cultivars. 'Jose Antonio' showed the highest weight and largest fruit length (24.10 cm), while 'Belize' showed the lowest. Their weight was superior to

TABLE 1.—*Cultivar, race, MIA/PI number, flower type and ease of skin peeling for 10 avocado cultivars from the USDA, ARS germplasm repository, Miami, FL, USA.*

Cultivar	Race[1]	MIA/PI[2] number	Flower type[3]	Skin Peeling
'Aycock Red 3'	WI	MIA 6915	B	Easy
'Belize'	WI	MIA 20023/317869	A	Easy
'Butler'	WI	MIA 35715	B	Easy
'Donalson'	WI	MIA 20024/317870	A	Semi-hard
'Ereguayquin #7'	G	MIA 34972	A	Easy
'Jose Antonio'	WI	MIA 17252/281924	B	Semi-hard
'Lima Late'	GXWI	MIA 19847	B	Easy
'Marcus'	GXW	MIA 35704	B	Semi-hard
'Orizaba 3'	G	MIA 34871/576516	A	Easy
'Tensen'	GXM	MIA 17114/234281	B	Easy

[1]WI= West Indian, G=Guatemalan, GXM= Guatemalan cross with Mexican, GXWI= Guatemalan x West Indian
[2]MIA= Miami accession number; PI=Plant Introduction number
[3]Type A or Type B flower

the values reached by cultivars from other locations, such as Venezuela (Gomez-Lopez, 2000, 2002) and Cuba. 'Belize' showed the lowest weight (Table 2). 'Tensen' and 'Lima Late' showed the largest seed content, whereas 'Donaldson' had the smallest seed (Table 2).

Following the descriptors for avocado issued by Bioversity International (IPGR, 1995), the cultivars were classified as, three obovate, two narrowly-obovate, two pyriform and three clavate shaped (Table 3). Seven cultivars had smooth texture, two were semi-rough, and one, rough. The rough texture is related to the development of extensive corky areas in the external fruit surface (Yahia, 2011) rather than the irregular surface exemplified by the 'Belize' and 'Ereguayquin #7' cultivars. 'Aycock Red', 'Tensen' and 'Orizaba 3' showed a purple peel (positive chromaticity value a, Table 3), which might be due to anthocyanin pigments as reported by Prabha et al. (1980); two cultivars had yellowish skin and the other cultivars were green (negative chromatic value a).

TABLE 2.—*Cultivars, fruit and seed weight, length and diameter, and pulp of 10 avocado cultivars at the Subtropical Horticulture Research Station at Miami, FL.*

Cultivar	Weight (g)	Length (cm)	Diameter (cm)	Pulp (g)	Seed (g)
'Aycock Red 3'	825.30 b[1]	18.80 b	9.92 b	770.40 b	55.20 f
'Belize'	610.80 e	17.67 c	9.19 b	519.20 f	91.33 c
'Butler'	747.76 c	19.30 b	8.94 b	658.00 d	90.24 c
'Donalson'	740.40 c	18.30 b	9.04 b	690.15 c	49.25 g
'Ereguayquin #7'	850.50 b	15.80 c	10.15 a	691.50 c	61.01 e
'Jose Antonio'	1,196.25 a	24.10 a	11.25 a	960.12 a	94.62 b
'Lima Late'	1,053.30 a	17.54 c	12.50 a	958.98 a	125.75 a
'Marcus'	780.55 c	16.75 c	10.85 a	715.23 b	65.23 d
'Orizaba 3'	682.21 d	11.22 d	8.657 c	630.11 e	52.10 f
'Tensen'	930.45 a	18.20 b	11.34 a	750.24 b	135.45 a

[1]Numbers within columns followed by the same letter are not significantly different ($p \leq 0.05$).

TABLE 3.—*Cultivar, shape[1], texture and color characteristics[2] of 10 avocado cultivars from the USDA, ARS germplasm repository, Miami, FL, USA.*

Cultivar	Shape	Texture	L^X	a^Y	b^Z
'Aycock Red'	Pyriform (7)	Soft	41.37 d[2]	-9.80 d	19.49 f
'Belize'	Narrowly obovate (5)	Semi-rough	37.35 e	-14.94 c	36.58 d
'Butler'	Clavate (8)	Soft	58.33 a	-10.00 d	48.71 b
'Donalson'	Clavate (8)	Soft	59.34 a	-18.99 b	52.13 a
'Ereguayquin #7'	Ovobate (6)	Soft	40.35 d	-24.96 a	41.87 c
'Jose Antonio'	Clavate (8)	Soft	54.36 b	-10.50 d	51.75 a
'Lima Late'	Ovobate (6)	Rough	42.76 c	-15.29 c	25.72 e
'Marcus'	Pyriform (7)	Soft	36.30 f	-14.86 c	40.27 c
'Orizaba 3'	Narrowly obovate (5)	Semi-rough	40.91 d	-6.95 e	12.16 g
'Tensen'	Ovobate (6)	Soft	39.92 d	-3.02 f	9.61 h

[1]Based on descriptors (IPGR, 1995)
[2]^{X}lightness/Luminosity, ^{Y}red/green chromaticity, ^{Z}yellow blue chromaticity
[3]Numbers within columns followed by the same letter are not significantly different ($p \leq 0.05$).

Most of the cultivars characterized were easy to hand peel, except 'Belize', 'Lima Late' and 'Ereguayquin #7'. 'Belize' showed a very adherent peel, and 'Lima Late' a very attached and easily torn skin. Most of the cultivars of WI origin showed an easy to peel and thin skin, yet most crossed cultivars with Guatemalan or pure Guatemalan race exhibit a tough and thick skin (Ayala Silva and Ledesma, 2014).

The highest point of fruit harvesting is the time when the greatest number of each cultivar ripen (Storey et al., 1973; Lee, 1982; Bergh et al., 1989) or meet international standards; that was three days for 'Butler'. 'Jose Antonio' and 'Marcus' ripened in three to four days, while the remaining seven ripened in four to seven days.

Selection of avocado cultivars is affected by fruit size, skin color and peel quality, weight with pulp percentages and oil content that the international market and consumers demand. For individuals with great interest in large size avocados with high pulp content, these four cultivars can be recommended: 'Jose Antonio', 'Lima Late', 'Butler' and 'Tensen'. However, if interested in the maturity period (shelf life), 'Jose Antonio' and 'Butler' should be avoided. This information should be useful in choosing among commercial cultivars, because the longer fruits take to reach their highest point of maturity, the longer their shelf life. The information provided will help individuals, researchers and growers to make the best use of these cultivars, to learn about diversity in avocados and aid stakeholders in deciding which avocado is most suitable for their needs.

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