Postharvest and Sensory Evaluation of Selected ‘Hass’ × ‘Bacon’ and ‘Bacon’ × ‘Hass’ Avocado Hybrids Grown in East-Central Florida

Cristina Pisani and Mark A. Ritenour¹

Department of Horticultural Sciences, University of Florida, Indian River Research and Education Center, 2199 S. Rock Road, Fort Pierce, FL 34945

Ed Stover, Anne Plotto, and Rocco Alessandro

USDA-ARS, U.S. Horticultural Research Laboratory, 2001 S. Rock Road, Fort Pierce, FL 34945

David N. Kuhn and Raymond J. Schnell

USDA-ARS, Subtropical Horticulture Research Station, 13601 Old Cutler Road, Miami, FL 33158

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Abstract. Avocado (*Persea americana* Mill.) is a high-value fruit that continues to increase in consumer demand. A population of ‘Hass’–‘Bacon’ hybrids was planted at USDA-ARS, Fort Pierce, as part of a study to find selections with good horticultural and postharvest quality traits for Florida. Extensive phenotypic data on quality were collected over 3 years. Ten selections were identified in 2014 and 2015 with promising fruit quality and postharvest shelf life characteristics and were tested in sensory panels using store-bought ‘Hass’ as the standard. In general, the selections had fruit quality similar to commercial ‘Hass’. Avocados that were most liked were described as creamy in texture with buttery and nutty flavor. Only one selection (R7T54 in 2014) and one store-bought control (‘Hass’ in 2015) were disliked, which was associated with greater firmness at the time of evaluation, likely relating to insufficient postharvest conditioning. Furthermore, CA ‘Hass’ commercial requirements for minimum dry matter (20.8%) were generally achieved by these selections under Florida conditions, ranging from 18.4% to 25.7%. This study identified 10 selections with composition and sensory quality similar to ‘Hass’ that are suitable for further testing and development in Florida.

The center of origin of wild avocado (*Persea americana* Mill.) is considered to be the humid tropical highlands of Central America (Honduras, Guatemala, and southern Mexico), and the three subspecies/races appear to have evolved in different climatic environments isolated from each other geographically (Kopp, 1966; Litz et al., 2005; Scora et al., 2002). *Persea americana* var. *drymifolia* race Mexican evolved in the highlands of south-central Mexico and is

adapted to tropical highlands (semitemperate climate). *P. americana* var. *guatemalensis* race Guatemalan is adapted to medium elevations in the tropics and, therefore, prefers subtropical climate. Lastly, *P. americana* var. *americana* race West Indian (or Antillean) is adapted to the lowlands and humid subtropics and, therefore, grows best in tropical areas (Litz et al., 2005; Popenoe, 1935). California and other regions with similar climates grow mostly Guatemalan and Guatemalan–Mexican hybrid avocados adapted to cooler winter temperatures. These avocados have a rough, leathery exocarp but the edible mesocarp portion has smooth texture with high oil content, up to 30% for some cultivars; the predominant cultivar on the market, ‘Hass’, is of this type (Barmore, 1976; Gibson, 1984; Lee et al., 1983; U.C. Riverside Avocado Database, 2016). On the other hand, the south Florida avocado industry grows cultivars that are better adapted to tropical climates with West Indian and West Indian–Guatemalan hybrid backgrounds (Crane et al., 2013; Litz et al., 2005). However, those types are less rich tasting because of lower oil content, have reduced shelf life, and have limited consumer acceptance compared with Guatemalan/Mexican types (Litz et al., 2005). Therefore, finding

a Guatemalan or Guatemalan–Mexican hybrid adapted to Florida’s subtropical climate would widen choices for Florida’s avocado industry and potentially permit production in areas where avocado has not been commercially produced.

Avocado fruit do not ripen while on the tree and only begin to ripen after harvest, making it difficult to identify fruit that are physiologically mature. There is a correlation between oil content and dry weight, with both increasing during maturation while fruit are still on the tree (Lee et al., 1983; Ozdemir and Topuz, 2004; Ratovohery et al., 1988). California maturity standards have been developed based on this correlation: a minimum of 20.8% dry matter content is required for ‘Hass’, with permitted harvest dates from 28 Nov. to 16 Jan., depending on the size (Anonymous, 1925; California Avocado Commission, 2016; Lee, 1981; Obenland et al., 2012). However, in Florida, maturity standards based on oil content or dry matter are not reliable because of the overall low oil content of West Indian avocados. A 1% or 2% variation in oil content could be critical for the maturity of some cultivars (Barmore, 1976). Furthermore, variability among cultivars and varietal differences in accumulation rates make maturity standards based only on oil content impractical in Florida. Instead, maturity standards are variety-specific, based on minimum fruit weight or diameter, or minimum days from full bloom (Barmore, 1976; Harding, 1954; Thurman and Campbell, 1959).

‘Hass’ is the most important avocado in the world with many traits that make it a favorite of growers, merchants, and consumers. Unfortunately, like most cultivars with Guatemalan and Mexican backgrounds, it does not perform well in south Florida avocado-producing areas. Disease pressure from high humidity, combined with insufficient chill hours, often do not allow adequate fruit yield. It would be very useful to identify a ‘Hass’-like cultivar that is well adapted to Florida as it would find a ready market. Because avocado produces hundreds of flowers for every fruit produced, conventional controlled crosses are very inefficient and largely impractical. As ‘Bacon’ is the primary pollinizer for ‘Hass’ (Kobayashi et al., 1996; Vrecenar-Gadus and Ellstrand, 1985), we acquired seeds and identified true hybrids for planting and evaluation. No comparable populations were available, but hybrids of this cross appear to be an adequate population for producing the type of selection we are targeting. Therefore, the objective of this project was to assess promising progeny from reciprocal crosses of ‘Hass’ and ‘Bacon’ in an attempt to identify a ‘Hass’-like selection suitable for east-central Florida. A preliminary sensory study was conducted in 2013 and indicated good acceptance of fruit from these hybrids grown at the Fort Pierce USDA farm (Pisani et al., 2014). In the current 2-year study, selections exhibiting good horticultural and postharvest qualities were identified and tested in sensory

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¹Corresponding author. E-mail: ritenour@ufl.edu.

panels using store-bought 'Hass' as the standard. Attributes assessed included dry matter and lipid content to determine whether these hybrids would meet California standards for avocado maturity when grown in east-central Florida.

Materials and Methods

Fruit description. Fruit were collected from selected trees that were among 350 unique 'Hass' × 'Bacon' and 'Bacon' × 'Hass' hybrid trees planted at the USHL-ARS, Fort Pierce, FL, in 2008 on double row beds in Riviera fine sand soil type. Trees originated from seeds collected from a commercial orchard in California by Dr. Raymond Schnell (SHRS-ARS, Miami), and molecular marker analysis confirmed which seedlings were true 'Hass'–'Bacon' hybrids before planting (Schnell et al., 2009). The trees were sprayed with horticultural oil and copper (CS-2005; Magna-Bon II, LLC, Okeechobee, FL), received foliar fertilization with a 20N–10P–20K soluble fertilizer every 2 weeks as part of a regular maintenance regimen, and received annual granular dry fertilizer (12N–2P–14K) at ≈ 226 – 270 kg·ha⁻¹. Soil applied metalaxyl (Ridomil; Syngenta Crop Protection LLC, Greensboro, NC) and foliar applied phosphonates (Lexx-A-Phos; Foliar Nutrients, Inc., Cairo, GA) for *Phytophthora* control were applied twice a year.

Phenotypic data. Sixteen fruit were collected randomly around each tree and analyzed for all phenotypic data of the entire hybrid population (data not shown) (Pisani, 2016). This phenotypic data were used to identify selections for the sensory study. About 20 additional fruit per tree were harvested for sensory analysis with phenotypic data being collected on three fruit per tree (Tables 1–3). Fruit were harvested from selected trees on 28 Oct. and 7 Nov. 2014, and 23 Oct. 2015, and transferred to the UF/IFAS, Indian River Research and Education Center postharvest laboratory in Fort Pierce, adjacent to the USHL-ARS, for ripening (defined here as postharvest conditioning of physiologically mature fruit to achieve adequate softening). Fruit was considered mature when it stopped growing and began falling from the tree. Fruit phenotypic data included fruit length, diameter and weight, fruit weight without seed, flesh percentage, and dry matter and lipid content. These measurements were performed on ripe fruit, after conditioning to reach 20–30 N firmness. Postharvest ripe fruit quality data also included intact fruit and pulp firmness, peel and pulp color, and postharvest rot and disorders.

Dry matter content of ripe fruit was determined. Five grams of ripe fruit mesocarp tissue were weighed onto a disposable petri dish, placed in an oven at 63 °C, and weighed every 2 days until no further weight loss was observed. Fruits were weighed every other day and percent water loss calculated. Flesh: seed ratio was determined from fresh flesh weight and seed weight. Fruit peel was not

Table 1. Phenotypic postharvest fruit data on selected avocado trees in 2014 and 2015 from a population of reciprocal crosses of 'Hass'–'Bacon' hybrids grown in east-central Florida. Measurements were made on three ripe fruit (20–30 N) per selection ($N = 3$).

	Wt (g)	Flesh wt (g)	Length (mm)	Width (mm)	Flesh (%)	Yield (fruit count)
2014						
Hass Mexico ^z	210.3 bc ^y	182.7 bc	94.8 bc	65.7 b	86.8 ab	N/A ^x
R8T9	198.1 bc	164.1 c	88.6 bc	64.6 b	82.8 a–c	59 d
R8T5	152.9 d	121.5 c	94.3 bc	57.4 b	79.5 a–c	284 a
R6T56	291.2 b	249.3 b	134.1 a	67.8 b	86.1 a–c	17 h
R5T56	449.8 a	412.4 a	148.1 a	79.4 a	91.7 a	12 i
Hass D.R. ^z	203.0 bc	171.5 bc	86.0 c	67.2 b	84.5 a–c	N/A
R8T54	180.7 c	135.8 c	85.0 c	62.4 b	75.1 bc	45 f
R8T18	161.8 cd	118.8 c	80.8 c	62.1 b	73.7 c	20 g
R8T11	163.4 c	123.4 c	84.2 c	62.0 b	75.8 bc	160 b
R7T54	208.5 bc	172.8 bc	104.2 b	63.5 b	82.9 a–c	110 c
R7T48	217.8 bc	185.8 bc	95.5 bc	66.2 b	85.3 a–c	56 e
Significance	*** ^w	***	***	***	**	***
SD	84.6	84.4	21.8	5.5	5.6	88.8
SE	25.5	25.4	6.6	1.7	1.7	26.8
2015						
Hass Chile ^z	168.4 b	145.8 b	89.5 c	61.1 c	86.6 ab	N/A
R8T21	171.4 b	144.0 b	86.0 c	63.6 bc	84.1 ab	40 c
R8T18	185.4 b	129.8 b	82.0 c	65.4 bc	70.0 c	212 a
R6T56	276.1 b	226.1 b	115.1 b	71.7 ab	82.0 b	91 b
R5T56	387.4 a	346.4 a	138.0 a	78.4 a	89.3 a	20 d
Hass Florida ^z	174.4 b	151.2 b	92.1 c	61.8 c	86.9 ab	N/A
Significance	***	***	***	**	***	***
SD	88.5	83.6	21.8	6.7	6.9	86.2
SE	26.7	25.2	6.6	2.0	2.1	26.0

^z'Hass' selections were included in both sensory panels. D.R. is Dominican Republic. All were store-bought except 'Hass' Florida which were from a tree grown alongside the numbered selections.

^yMeans followed by the same letter within each column do not differ significantly according to Tukey's studentized range (HSD) test ($P \leq 0.05$).

^xN/A indicates data not available.

^w*, **, *** indicate significant at $P \leq 0.01$ and 0.001 , respectively.

Table 2. Peel and pulp color of ripe avocado fruit in 2014 and 2015. Measurements were made on three ripe fruit per selection ($N = 3$).

	Lightness (L*)		Hue (h°)		Chroma (C*)	
	Peel	Pulp	Peel	Pulp	Peel	Pulp
2014						
Hass Mexico	28.7 bc ^z	79.0 a	67.3 bc	102.6 ab	6.4 cd	35.8 de
Hass D.R.	29.8 bc	77.6 ab	96.7 ab	103.3 a	9.3 b–d	38.3 c–e
R5T56	26.2 c	74.0 a–c	60.5 c	94.3 bc	3.0 d	41.1 bc
R8T5	29.3 bc	72.1 bc	97.7 a	95.8 a–c	5.5 cd	38.3 c–e
R8T54	32.7 ab	73.6 a–c	103.8 a	93.6 a	9.8 a–d	40.2 b–d
R6T56	31.3 a–c	75.8 ab	106.3 a	95.0 a–c	9.2 b–d	41.8 bc
R8T11	32.8 ab	69.2 c	106.7 a	97.1 a–c	12.9 a–c	35.8 de
R8T9	35.4 a	76.7 ab	106.8 a	95.7 a–c	14.0 ac	38.9 c–e
R8T18	35.9 a	74.6 a–c	110.0 a	98.0 a–c	19.5 a	35.5 e
R7T48	32.4 ab	75.1 a–c	112.6 a	95.5 a–c	11.6 a–d	43.7 ab
R7T54	35.9 a	75.6 ab	123.0 a	100.5 a–c	17.4 ab	47.0 ab
Significance	*** ^y	**	***	**	***	***
2015						
Hass Florida	32.4	78.7	92.3	95.0 bc	14.3	45.0 ab
Hass Chile	28.2	79.9	53.2	103.8 ab	5.5	39.5 b
R5T56	26.1	77.1	64.7	93.6 c	3.8	44.2 ab
R8T18	32.2	78.2	84.4	96.9 bc	12.7	41.7 ab
R6T56	34.2	78.6	118.7	95.9 bc	17.7	46.8 a
R8T21	35.0	76.3	123.8	100.3 ab	16.9	46.6 a
Significance	NS	NS	NS	***	NS	**

^zMeans followed by the same letter within a column do not differ significantly according to Tukey's studentized range (HSD) test ($P \leq 0.05$).

^yNS, **, *** indicate nonsignificant or significant at $P \leq 0.01$ and 0.001 , respectively.

removed from the fruit and was included in flesh percentage and gross fruit weight.

Ripe fruit peel color was measured using a Minolta Colorimeter (CR-400; Konica Minolta Sensing, Inc., Japan) at three equidistant locations around the equator of each fruit. The pulp color was measured on 1.5-cm cross section slices from the stem and blossom

end of each fruit. The Colorimeter was calibrated with a white standard tile, and the CIELAB values L* (lightness, where 0 = black, 100 = white), a* (green to red component), and b* (yellow to blue component) were measured. The chroma (C*) and hue (h°) were calculated from the measured a* and b* values using the formulas $C^* = (a^{*2} + b^{*2})^{1/2}$

Table 3. Whole fruit and pulp firmness of ripe avocado fruit in 2014 and 2015. Firmness was taken at the stem end and blossom end of cross section slices. *N* = 3 for each selection.

	Peak force ^z (N)	Mean force ^y (N)	Stem peak force ^x (N)	Stem mean force (N)	Blossom peak force ^w (N)	Blossom mean force (N)
2014						
Hass D.R.	21.3 ab ^v	10.1 ab	4.5 ab	3.2 b	4.4	3.5
Hass Mexico	12.9 c	6.6 bc	2.5 b	1.9 b	2.9	2.6
R5T56	11.6 c	5.5 c	3.3 b	2.6 b	3.7	2.5
R6T56	15.6 bc	8.1 bc	4.5 ab	3.5 ab	2.6	2.1
R7T48	17.8 bc	8.5 bc	3.9 b	2.9 b	2.8	1.9
R7T54	28.3 ab	12.9 a	9.0 a	6.8 a	3.9	3.3
R8T11	21.9 ab	9.9 ab	4.4 ab	3.5 ab	5.0	3.7
R8T18	15.2 bc	7.8 bc	2.7 b	1.8 b	2.5	2.0
R8T5	17.9 bc	9.1 a–c	3.9 b	3.0 b	4.0	3.2
R8T54	13.4 c	6.4 bc	4.2 ab	3.0 b	3.7	2.7
R8T9	15.5 bc	7.8 bc	3.4 b	2.3 b	3.0	2.3
Significance	***u	***	*	**	NS	NS
2015						
Hass Florida	30.4 ab	15.4 a	4.8 ab	3.9 bc	8.7 b	6.9 b
Hass Chile	35.3 a	15.3 ab	26.9 a	15.3 a	33.4 a	19.7 a
R5T56	17.9 c	9.5 b	21.8 ab	14.1 ab	6.4 b	4.9 b
R6T56	23.4 bc	13.3 ab	7.8 ab	6.3 a–c	3.8 b	2.6 b
R8T18	21.3 bc	10.7 ab	3.2 b	2.4 c	3.4 b	2.9 b
R8T21	20.3 bc	10.5 ab	13.1 a	7.3 a	4.2 b	3.1 b
Significance	***	*	*	**	***	***

^zPeak force is the hardness value that occurs during the first compression of whole fruit and expresses the combined effect of peel thickness and flesh firmness just beneath the peel.

^yMean force is the mean of the maximum force for two orientation points of compression on the whole fruit and expresses the flesh firmness with some influence of peel thickness.

^{x,w}Pulp firmness measurements were made at the stem and blossom ends of 1.5 cm slices with peel. Slices were placed on the Texture Analysis system base where a 8-mm diameter convex probe and 50 kg load cell were used to measure pulp firmness in the center of the tissue.

^vMeans followed by the same letter within a column do not differ significantly according to Tukey's studentized range (HSD) test (*P* ≤ 0.05).

^uNS, *, **, *** indicate nonsignificant or significant at *P* ≤ 0.05, 0.01, and 0.001, respectively.

and $h^* = \arctan(b^*/a^*)$ (McGuire, 1992). The results are presented as *L**, *h°*, and *C** (color saturation; degree of departure from gray toward pure chromatic color) with hue values of 90° representing a yellow color and 180° a green color.

Fruit firmness was determined every other day, on three fruit per test tree, by a non-destructive compression test on whole, unpeeled fruit using a Stable Micro Systems Texture Analyzer (TA-XT2i; Texture Technologies Corp., Scarsdale, NY) fitted with a flat plate (5-cm diameter) and 50-kg load cell. After establishing zero force contact between the probe and the equatorial region of the fruit, two measurements were taken per fruit while rotating 90° between measurements. The probe compressed the fruit 2.5 mm with a crosshead speed of 20 mm·min⁻¹. Once whole fruit firmness reached 20–30 N, pulp firmness was determined by using a destructive compression test on the three ripe fruit per test tree. The stem and blossom ends of the fruit with peel were removed as 1.5-cm slices and placed on the texture analysis system base where an 8-mm diameter convex probe and 50-kg load cell were used to measure pulp firmness in the center of the tissue. After establishing zero force contact between the probe and the mesocarp tissue, the probe was driven with a crosshead speed of 50 mm·min⁻¹ for 5-mm depth, puncturing the mesocarp tissue in an inside-out (seed cavity to extremity) direction. The maximum force was recorded.

Internal quality was evaluated on the same fruit used in destructive tests. Fruits were cut in half and assessed relative to the

outer and cut surfaces displaying a disorder or rot, using the rating scale from the International Avocado Quality Manual (White et al., 2009) where 0 = healthy, 0.5 = 5%, 1 = 10%, 1.5 = 15%, 2 = 25%, 2.5 = 33%, and 3 = 50% affected by disorders. This rating included common disorders such as vascular browning, stem end rot, and body rot, as well as less common disorders such as uneven ripening, tissue breakdown, seed cavity browning, and vascular leaching. This rating did not include flesh bruising that may have been caused by the firmness test.

About 500 mg of ripe mesocarp tissue from each of two fruit used in destructive tests were collected for fatty acid analysis. Two extractions were conducted on each fruit, including commercial 'Hass' as a standard. Common fatty acid methyl esters (FAMES) were identified and quantified using GC-FID (Pisani, 2016). The oil content was determined by dividing lipid weight after extraction by the mesocarp fresh tissue weight and expressed as a percentage of the mesocarp tissue fresh weight.

Sensory evaluation. A preliminary sensory study was conducted in Dec. 2013 (Pisani et al., 2014) to practice fruit preparation and ballot development, based on a study by Obenland et al. (2012). In 2014, nine avocado selections were chosen based on good horticultural and postharvest traits and were evaluated in two taste panels in consecutive weeks. Horticultural traits included fruit set after bloom, yield, fruit size, and seed to flesh ratio. Postharvest traits included fruit dry matter, color, rots, and disorders. Four selections

were evaluated in 2015. All taste panels included store-bought 'Hass' as a reference, with various origins as available (Mexico and Dominican Republic in the first and second panel, respectively, in 2014, and Chile in 2015).

Fruit for each selection and store-bought unripe 'Hass' were conditioned at 22 °C with 87–95 µL·L⁻¹ ethylene for different durations and then placed in a cold room (10 °C) to manage softening, targeting all fruit to be between 20 and 30 N (defined here as "ripe") at the time of sensory evaluation. Whole fruit firmness was measured every other day as described above, until reaching the fully ripe stage. Fruit were transferred to the USDA-ARS USHRL for washing, sanitizing, and sensory evaluation. Fruits were washed with 200 mL of commercial fruit detergent (Fruit Cleaner 395; JBT Food Tech, Lakeland, FL) per ≈10 L lukewarm water, followed by a 3 min sanitizing dip in 100 µL·L⁻¹ peroxyacetic acid (PAA) (Peraclean® 15; Degussa, ON, Canada). Fruit were air-dried for at least 2 h at room temperature before placing at 13.5 °C before sensory evaluation the next day.

Panelists consisted of personnel from the IREC and USDA-ARS USHRL, as well as Florida commercial avocado and citrus industry representatives and consisted of 55 panelists each year. Fruit were prepared just before tasting by cutting each avocado vertically from the stem to blossom end, separating the halves, and removing the seed. Flesh at the stem and blossom ends, above and below the seed, was discarded and the remaining portions were peeled and cubed. Three pieces (≈2 cm³ each) were placed into 30-mL plastic cups labeled with three-digit random numbers for each selection and served at room temperature (≈21 °C). The tasting was conducted in individual booths and under red lighting. Panelists rated overall liking using a 1 to 9 points hedonic scale with 1 being "dislike extremely" and 9 being "like extremely." Then, they completed a multiple choice questionnaire to best describe each sample. Textural descriptors were as follows: firm, mushy, stringy, gritty, creamy, smooth, dry, watery, and oily. Flavor and aromatics descriptors were as follows: bland, grassy, woody, piney-terpiny, sweet, fruity, nutty, buttery, savory, oily-fatty, and rancid. Those descriptors were selected based on previous research in California and the preliminary panel in 2013 (Obenland et al., 2012; Pisani et al., 2014). Panelists were also instructed to take a bite of carrot or cracker and drink some water to rinse their palates between each sample (Obenland et al., 2012).

Statistical analysis. All experiments except sensory evaluations were conducted in a completely randomized design. Three fruit were used as replicates for each individual tree in the population. Statistical procedures were performed using Statistical Analysis Software (SAS) version 9.4 (SAS Institute Inc., Cary, NC). Differences between means were determined using Tukey's studentized range test [honest significant difference (HSD)].

For sensory evaluation, sample servings were arranged in a William's design (balanced block) with each selection representing a treatment and panelists as the replicates. Data collection and analysis were performed using Compusense five® sensory software (Guelph, ON, Canada). Data from the 9-point hedonic scale were analyzed using the Kruskal–Wallis test, nonparametric equivalent of ANOVA. Mean separation between treatments was performed with the Dunn test with Bonferroni correction. Data from the multiple choice questionnaire were analyzed using the Cochran Q test, with multiple comparisons between samples performed with the Marascuilo test. All sensory statistics were performed using XLStats Version 2014.5.01 (Addinsoft, Paris, France).

Results and Discussion

Phenotypic data. Phenotypic data spanned a wide range among the hybrid selections. During both years, fruit of selection R8T18 were the smallest and R5T56 the largest in physical volume with lowest and highest flesh weight, respectively (Table 1). In addition, R8T18 and R5T56 had the lowest and highest flesh percentage, respectively. Field and post-harvest data on Florida-grown 'Hass' ('Hass' Florida) were not collected in 2014 as fruit was unavailable. Trees produced as little as 12 and 20 fruit (R5T56) each year to as many as 284 fruit (R8T5) in 2014 and 212 fruit (R8T18) in 2015, respectively (data not shown). Overall, trees with larger fruit tended to bear less fruit per tree, and trees with smaller fruit had more fruit per tree.

Selections in 2014 had peel that was dark brown in color when ripe similar to 'Hass' samples from the Dominican Republic ('Hass' D.R.), except for R5T56, which was more yellow ($h^{\circ} = 60.5$) and was more comparable with 'Hass' samples from Mexico (Table 2). There was no significant difference in pulp color among the selections. Lightness and C^* values indicate that all fruit selections had very dark peel color and were comparable with 'Hass' except for R7T54, R8T18, and R8T9 that were significantly different in L^* and R8T18 in C^* . Peel C^* values were very low, indicating that the hues were very far from pure and actually nearly gray. Selections in 2015, including store-bought 'Hass' from Chile and 'Hass' Florida, also had peel that was dark brown in color and showed no significant differences in peel or pulp color, except for pulp of R5T56 that had the most yellow pulp when compared with other selections (h° value closer to 90) (Table 2).

In 2014, whole fruit firmness of ripe 'Hass' D.R. was among the firmest (21.3 N) and 'Hass' from Mexico among the softest (12.9 N) together with R5T56 (11.6 N) and R8T54 (13.4 N) (Table 3). There were no significant differences in pulp firmness at blossom ends between the selections and 'Hass' in 2014, ranging from 2.5 N (R8T18) to 5.0 N (R8T11) peak force and from 1.9 N (R7T48) to 3.7 N (R8T11) mean force (data not shown). Selection R7T57 was the firmest at

Table 4. Average fatty acid (FAME) percentage composition ($\pm$ SE) of avocado pulp oil of individual selections and 'Hass' standards evaluated in the 2014 and 2015 taste panels. Two fruits per selection and two samples per fruit were used in fatty acid analysis of individual selections, $N = 4$. Total fatty acid percent was done on avocado pulp of all Florida selections in 2014 ($N = 44$) and 2015 ($N = 24$).

Year	Selection	Palmitate $C_{16:0}$ (%) ^a	Palmitoleate $C_{16:1}$ (%) ^a	Stearate $C_{18:0}$ (%) ^a	Oleate $C_{18:1}$ (%) ^a	Linoleate $C_{18:2}$ (%) ^a	Linolenate $C_{18:3}$ (%) ^a	Oil content (% of fresh weight) ^b	Dry matter ^c (%)
2014	Hass Mexico	25.0 $\pm$ 1.86 d-f ^w	11.9 $\pm$ 2.08 bc	0.4 $\pm$ 0.09 b	51.3 $\pm$ 4.51 a	11.4 $\pm$ 0.73 f	0.1 $\pm$ 0.07	14.2 $\pm$ 2.09 a-c	24.0
	R8T9	23.5 $\pm$ 0.07 ef	6.4 $\pm$ 0.52 ef	0.6 $\pm$ 0.03 ab	51.4 $\pm$ 0.59 a	18.1 $\pm$ 0.03 c-e	0.0 $\pm$ 0.00	13.6 $\pm$ 0.29 a-c	21.9
	R8T5	23.2 $\pm$ 0.52 ef	8.2 $\pm$ 0.40 de	0.6 $\pm$ 0.01 ab	49.3 $\pm$ 1.93 ab	18.4 $\pm$ 0.97 b-e	0.3 $\pm$ 0.06	11.8 $\pm$ 0.58 c	22.5
	R6T56	29.2 $\pm$ 0.07 a-c	14.5 $\pm$ 1.89 ab	0.6 $\pm$ 0.00 ab	39.7 $\pm$ 0.31 cd	15.9 $\pm$ 1.46 e	0.2 $\pm$ 0.04	16.6 $\pm$ 0.83 ab	25.7
	R5T56	18.1 $\pm$ 0.84 g	4.9 $\pm$ 0.53 f	0.6 $\pm$ 0.02 ab	50.8 $\pm$ 1.68 a	25.5 $\pm$ 1.30 a	0.3 $\pm$ 0.05	12.8 $\pm$ 1.07 bc	24.0
	Hass D.R.	31.3 $\pm$ 1.08 a	14.8 $\pm$ 2.35 ab	0.2 $\pm$ 0.17 c	36.6 $\pm$ 0.47 d	17.2 $\pm$ 1.92 de	0.0 $\pm$ 0.00	9.5 $\pm$ 1.78 c	23.6
	R8T54	22.6 $\pm$ 0.20 f	7.0 $\pm$ 0.02 ef	0.6 $\pm$ 0.00 a	49.2 $\pm$ 2.52 ab	20.3 $\pm$ 2.05 b-d	0.3 $\pm$ 0.29	17.3 $\pm$ 0.60 a	25.0
	R8T18	27.2 $\pm$ 1.33 b-d	15.5 $\pm$ 0.02 a	0.5 $\pm$ 0.03 ab	35.1 $\pm$ 0.84 d	21.5 $\pm$ 0.38 a-c	0.2 $\pm$ 0.16	13.2 $\pm$ 0.47 a-c	21.4
	R8T11	29.3 $\pm$ 1.33 ab	10.6 $\pm$ 0.50 cd	0.5 $\pm$ 0.05 ab	34.4 $\pm$ 1.14 d	25.0 $\pm$ 0.25 a	0.0 $\pm$ 0.00	10.2 $\pm$ 0.41 c	19.4
	R7T54	22.7 $\pm$ 1.12 f	11.3 $\pm$ 1.51 bc	0.5 $\pm$ 0.01 ab	45.1 $\pm$ 1.40 bc	20.1 $\pm$ 0.90 b-d	0.3 $\pm$ 0.33	11.8 $\pm$ 0.25 c	18.4
	R7T48	26.2 $\pm$ 0.77 c-e	12.9 $\pm$ 0.52 a-c	0.6 $\pm$ 0.03 a	37.9 $\pm$ 1.24 d	22.3 $\pm$ 0.14 ab	0.1 $\pm$ 0.12	13.2 $\pm$ 0.78 a-c	22.1
Significance		*** ^v	***	***	***	***	NS	***	NS
Total fatty acid (%) $N = 44$		24.89 $\pm$ 0.50	10.71 $\pm$ 0.49	0.49 $\pm$ 0.02	44.93 $\pm$ 0.94	19.23 $\pm$ 0.59	0.15 $\pm$ 0.04		SE = 0.7
2015	Hass Chile	17.0 $\pm$ 0.99 c	4.3 $\pm$ 0.75 d	0.3 $\pm$ 0.00	63.5 $\pm$ 1.41 a	14.0 $\pm$ 0.25 d	1.0 $\pm$ 0.08 ab	16.0 $\pm$ 1.83 a	26.0
	Hass Florida	32.9 $\pm$ 0.27 b	18.2 $\pm$ 1.32 ab	0.5 $\pm$ 0.07	22.9 $\pm$ 0.92 d	24.4 $\pm$ 0.16 ab	1.1 $\pm$ 0.09 a	9.9 $\pm$ 1.24 b	23.8
	R8T21	37.2 $\pm$ 0.58 a	20.8 $\pm$ 1.14 a	0.5 $\pm$ 0.16	19.4 $\pm$ 0.12 e	21.4 $\pm$ 1.58 bc	0.7 $\pm$ 0.10 ab	11.7 $\pm$ 0.10 ab	23.5
	R8T18	29.7 $\pm$ 0.53 b	16.0 $\pm$ 1.21 bc	0.4 $\pm$ 0.03	31.8 $\pm$ 0.49 c	21.4 $\pm$ 1.26 c	0.7 $\pm$ 0.02 b	12.9 $\pm$ 0.82 ab	20.0
	R6T56	29.8 $\pm$ 2.16 b	15.3 $\pm$ 0.94 c	0.5 $\pm$ 0.04	32.9 $\pm$ 0.15 c	20.7 $\pm$ 2.76 c	0.8 $\pm$ 0.15 ab	13.3 $\pm$ 1.20 ab	22.5
	R5T56	20.1 $\pm$ 1.81 c	3.6 $\pm$ 0.28 d	0.5 $\pm$ 0.03	48.6 $\pm$ 1.02 b	26.1 $\pm$ 0.30 a	1.0 $\pm$ 0.20 a	10.4 $\pm$ 0.59 b	22.0
Significance		***	***	NS	***	***	**	***	NS
Total fatty acid (%) $N = 24$		25.91 $\pm$ 1.37	11.63 $\pm$ 1.25	0.45 $\pm$ 0.02	40.01 $\pm$ 2.83	21.08 $\pm$ 0.75	0.91 $\pm$ 0.05		SE = 0.6

^aPercentage of total FAME.

^bTotal oil content was calculated as the percentage of lipid weight per total mesocarp weight.

^cDry matter was determined from ripe fruits (20–30 N) with 5 g of mesocarp tissue placed in an oven set at 63 °C until no further weight loss was observed. $N = 2$ per selection.

^wMeans followed by the same letter within a column do not differ significantly according to Tukey's studentized range (HSD) test ($P \leq 0.05$).

^v*, **, *** indicate significant at $P \leq 0.05$, 0.01, and 0.001, respectively.

the stem end (9.0 N) and comparable with 'Hass' D.R. (4.5 N). In 2015, 'Hass' from Chile had the greatest whole fruit firmness. Indeed, these fruit were store-bought as a reference for the taste panel and did not respond as well as the tree-harvested fruit to conditioning (Table 3). Peak force of blossom ends ranged from 3.4 N (R8T18) to 33.4 N ('Hass' Chile) and from 2.6 N (R6T56) to 19.7 N ('Hass' Chile) mean force in 2015.

Dry matter, picking date, fruit size, and oil content are characteristics used as avocado maturity indices depending on cultivar and geographic location (Lee et al., 1983). The percent dry matter has been the main maturity index in most avocado-producing areas, except Florida. For Florida avocados, maturity standards were set with the help of taste panels and are based on fruit size and days after bloom. In California, major cultivars such as 'Bacon' and 'Hass', both Guatemalan-Mexican hybrids (parents of crosses used in this study), must meet the maturity standard minimum dry matter contents of 17.7% and 20.8%, respectively, which approximates an oil content of 8% (Yahia and Woolf, 2011). All of the selections in the current study met California minimum dry matter percentages for either 'Bacon' or 'Hass' or both in both years (Table 4). Because dry matter was measured on ripe fruit, water loss was taken into account. Dry matter of the avocado selections after ripening ranged from 18.4% (R7T54) to 25.7% (R6T56) in 2014 and from 20.0% (R8T18) to 26.0% ('Hass' Chile) in 2015 (Table 4). Among the selections evaluated, mean water loss rate ranged 0.23–0.35 g/d in 2014 and 0.43–0.44 g/d in 2015 over a 5-d period, representing about 1% weight loss between harvest and the end of ripening when dry matter was measured. Thus, dry matter at harvest would be $\approx 0.2\%$ lower than the values reported for ripe fruit in this study because of water loss. Store-bought 'Hass' had 23.6% (Dominican Republic) and 24.0% (Mexico) dry matter in 2014 and 26.0% (Chile) dry matter in 2015. Dry matter of the test selections in this study harvested in October–November was similar to those of California 'Hass' avocados harvested in April–May (Obenland et al., 2012). Selections R8T11 and R7T54 had the lowest dry matter (19.4% and 18.4%, respectively) which was below the California 'Hass' maturity standard. As the dry matter content increases, the longer the fruit remain on the tree, and the optimal harvest date would likely need to be determined for individual selections. In California, avocados can be stored on the tree, with 'Hass' harvests occurring from April through October (typically 11–16 months after fruit set) and 'Bacon' from November through March (typically 6–10 months after fruit set). Based on the growth data of test selections in this study (data not shown), the fruit stopped growing at the beginning of October (7 months after fruit set) in both years, which means the fruit would have met California maturity standards at least by October and December, well before 'Hass' fruit matures in California.

Having accurate maturity standards is important because when picked too early, avocado eating quality even when ripened is associated with grassy aftertaste, bland flavor, and rubbery texture, watery texture, or both (Obenland et al., 2012; Yahia and Woolf, 2011). In California, fully mature, ripened fruit were associated with creamier, less watery texture, and less grassy flavor (Obenland et al., 2012). The study results were similar to other published reports (Obenland et al., 2012) where the most watery selections (e.g., R7T54) had the lowest dry matter content and were the firmest when ripe (Table 3). Therefore, palatability is likely associated with inherent qualities of the selections and their stages of ripeness. Fruit of R7T54 appeared to be fully mature and ripe when sampled whereas 'Hass' Chile fruit appeared to be fully mature but did not respond to conditioning to achieve target softness for best palatability.

Nine selections in 2014 and four selections in 2015 were chosen for sensory evaluation because in earlier evaluations the fruit had acceptable flesh percentage (Table 1) compared with the other selections and developed low incidence of postharvest disorders and rot (data not shown). Most evaluated selections exhibited low levels of disorders such as body rot, vascular browning, seed cavity browning, and uneven ripening in 2014 and 2015. Tissue breakdown and stem end rot were the most common maladies ranging from 5% (R6T56)

to 50% (R8T18) in both seasons (data not shown). Tissue breakdown may be associated with stem end and body rot fungi such as *Colletotrichum gloeosporioides*, a causal agent of anthracnose, which may be exacerbated because of the hot and humid climate of Florida (Menge and Ploetz, 2003; Ploetz et al., 1994).

Fatty acid analysis. Fatty acids analyzed in this study were chosen based on previous literature as the most common fatty acids in the pulp of avocado, albeit as many as 22 fatty acids were identified in avocado mesocarp in a study by Bora et al. (2001). Avocados are rich in the monounsaturated fatty acid oleate ($C_{18:1}$), which was the most abundant fatty acid found in most selections in both years, with 45% of total fatty acid in 2014 and 40% in 2015 (Table 4). Palmitate ($C_{16:0}$), linoleate ($C_{18:2}$), and palmitoleate ($C_{16:1}$) were the second, third, and fourth most abundant fatty acids. Stearate ($C_{18:0}$), linolenate ($C_{18:3}$), and myristate ($C_{14:0}$) were only found in small or trace amounts. Oil composition changes seasonally as fruit develops (Du Plessis, 1979) where oleate generally increases whereas palmitate and linoleate contents decrease. Oleate was the third most prevalent fatty acid in two selections (field-grown 'Hass' and R8T21) (Table 4), which can indicate lack of maturity. However, these changes can vary with cultivar and climate (Du Plessis, 1979).

Fig. 1. Percentage of panelists in 2014 (A) and 2015 (B) characterizing the avocado flesh texture using the indicated descriptors. Store-bought 'Hass' from Mexico, the Dominican Republic (D.R.), or Chile, depending on availability, served as commercial standards. Sensory evaluation included 55 panelists each year. Means marked with the same letter do not differ significantly according to Cochran Q range test ($P \leq 0.05$) with multiple comparisons between samples performed with the Marascuilo test.

Oil content of fruit varies with cultivar and ecological origin. The test selections in this study ranged from 10.2% oil content (R8T11) to 17.3% (R8T54) in 2014 and 2015 (Table 4) and all met the historical minimum 8% oil standard used in California for Mexican- and Guatemalan-type cultivars. Store-bought ‘Hass’ ranged from 9.5% to 16.0% and were not very different from the selections.

Avocado fruit is one of the most important natural sources of monounsaturated fatty acids such as oleate, which is known to lower “bad” cholesterol (low density lipoprotein), and its low content of saturated fatty acids makes avocado an excellent source of healthy fat (Ozdemir and Topuz, 2004; Ratovohery et al., 1988). For ‘Hass’, Ozdemir and Topuz (2004) reported that oleate content ranged from 47.2% to 59.5%, depending on harvest date, whereas in the current study, oleate content ranged from 19.4% to 63.5% and was similar to other studies reporting that oleate, palmitate, palmitoleate, and linoleate are the major fatty acids in avocado pulp (Bora et al., 2001; Moreno et al., 2003; Ozdemir and

Topuz, 2004; Pacetti et al., 2007; Ratovohery et al., 1988). Similar results were also found in the fatty acid analysis for the whole ‘Bacon’ × ‘Hass’ and ‘Hass’ × ‘Bacon’ hybrid population (Pisani, 2016).

During the 2014 season, store-bought ‘Hass’ from Mexico had 40% higher oleate values compared with ‘Hass’ from the Dominican Republic and also had 49% higher total fatty acid content (Table 4). For the 2015 season, ‘Hass’ from Chile had the highest oleate content among the materials studied. Florida-grown ‘Hass’ and R8T21 were the only avocados tested in which oleate was not the most abundant fatty acid, with palmitate exceeding oleate by about 50% in those two genotypes.

Sensory evaluation. In 2014, all of the selections were comparable with commercial ‘Hass’ from either D.R. or Mexico for overall liking (between 5.45 and 6.11 on a 1–9 point scale), with the exception of R7T54 (4.60) that was liked significantly less than both store-bought ‘Hass’ fruits (6.11 and 5.91). In 2015, R6T56 had the highest preference rating (6.18), but was not significantly different

from other selections (5.35–5.95). However, ‘Hass’ from Chile had the lowest rating (4.84 = dislike slightly), significantly lower than R6T56 (6.18), R8T18 (5.95), and R8T21 (5.91) but not from R5T56 (5.35). Both years, fruit that had lower overall liking ratings had higher firmness, indicating they did not respond to pretaste conditioning as well as the other fruit. Both R7T54 and ‘Hass’ from Chile had a firmness level close to or greater than the 30 N maximum target for whole fruit firmness (Table 3).

Descriptors used in the sensory evaluation were based on those published by Obenland et al. (2012) for California avocado. In both 2014 and 2015, more than 50% of panelists characterized each of the evaluated selections as creamy, with the exception of R8T11 and R7T54 in 2014 (Fig. 1A) and ‘Hass’ from Chile in 2015 (Fig. 1B). Selection R7T54 was rated as the most firm (70% of responses), most watery (40% of responses), and bland in 2014 (Figs. 1A and 2A), and ‘Hass’ from Chile was distinct from Florida selections by its firmness (84% of responses) and dryness

Fig. 2. Percentage of panelists in 2014 (A) and 2015 (B) characterizing the avocado flesh flavor using the indicated descriptors. Store-bought ‘Hass’ from Mexico, the Dominican Republic (D.R.), or Chile, depending on availability, served as commercial standards. Sensory evaluation included 55 panelists each year. Means marked with the same letter do not differ significantly according to Cochran Q range test ($P \leq 0.05$) with multiple comparisons between samples performed with the Marascuilo test.

(25% of responses) (significantly different from other selections) in 2015 (Figs. 1B and 2B) and were the samples least liked. Greater firmness is essentially equivalent to lower ripeness, and less ripe fruit tend to have more of a grassy aftertaste, bland flavor, and rubbery texture, watery texture, or both (Harding, 1954; Obenland et al., 2012; Yahia and Woolf, 2011). On the contrary, “creamy” and “buttery” characterized most selections in 2014, except for R8T11 and R7T54 (Fig. 1A), and was most associated with R6T56 in 2015 (Fig. 2A). These attributes indicate higher eating quality and optimum ripeness (Obenland et al., 2012). These authors also showed a general decline in “grassy” flavor corresponding to lower hexanal produced by the fruit; our data indicate similar trends in 2015, with R6T56 being characterized by the highest creaminess and the lowest grassy flavor (Fig. 2A and B). Only a low percentage of panelists (<10%) used the terms stringy, gritty, dry, or watery to characterize any of the selections (except R7T54 in 2014).

Among the flavor attributes, sweet, nutty, and buttery showed differences between selections in 2014 and likewise grassy, woody/piney, buttery, and rancid in 2015 (Fig. 2A and B). “Sweet” was the most selected attribute for ‘Hass’ from D.R. and least selected for R6T56, R5T56, R8T54, and R7T54 in 2014. “Nutty” was highest for R7T48, R8T18, and R8T54 in 2014. “Buttery” was highest for R8T18 in 2014, and for R6T56 in 2015. It is interesting to note that in spite of high firmness, low creaminess, nutty, and buttery flavor, selection R8T11 still had overall liking rating (5.49) comparable with ‘Hass’ (5.91–6.18). It was selected as “sweet” by 20% of the panelists.

Only three selections were tested in both years, because of fruit availability. Results were comparable for R5T56 and R8T18, but R6T56 was considered as firmer and less buttery in 2015 as compared with 2014. Not all panelists who tasted in 2014 repeated as panelists in 2015, and in addition to normal annual crop variation, standardizing fruit maturity for taste panels remains a challenge. Nevertheless, based on the results of this study, the selections evaluated appear to have fruit quality similar to commercial ‘Hass’.

Conclusion

The selections evaluated in this study met the minimum maturity requirements set for ‘Hass’ and ‘Bacon’ in California, but further analysis is needed to determine optimal maturity indices for individual selections. Because almost all the selections evaluated were of similar acceptability compared with store-bought and Florida-grown ‘Hass’, these show promise for Florida production. However,

further studies evaluating greater numbers of trees are needed to evaluate consistency of tree performance over multiple growing sites and the effect of harvest date on oil content and consumer acceptance of these selections.

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