Describing Quality and Sensory Attributes of 3 Mango (*Mangifera indica* L.) Cultivars at 3 Ripeness Stages Based on Firmness

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Abstract: To determine the ideal ripening stage for consumption of the mango cultivars, "Ataulfo," "Haden," and "Tommy Atkins"; fruits at 3 flesh firmness levels (ripeness stages) were evaluated by a trained panel using descriptive analysis after instrumental measurements were made. After harvest, all fruits were ripened to allow softening and quality and sensory attribute changes. Ripening changes during softening of Ataulfo mangos were expressed by a characteristic increase in the perception of "tropical fruit" and "peach" aromas, an increase in "juiciness," "sweetness," and "tropical fruit" flavor, while "fibrousness," "chewiness," and "sourness" decreased. Similar desirable sensory changes were also detected during softening of Haden mangos; an increase in tropical fruit and peach aromas, sweetness and tropical fruit flavor, and a decrease in chewiness, sourness, and bitterness. Softening of Tommy Atkins mangos was followed by reduced chewiness and sourness and increased peach aroma. Softening of all cultivars was followed by decreased sourness and titratable acidity (TA) and increased soluble solids concentration (SSC) and SSC:TA ratio. The results indicate that mango ripening leads to increased expression of sensory attributes such as tropical fruit and peach aromas, tropical flavor, and sweetness that have been related to improved eating quality and these final changes in sensory quality attributes are specific for each cultivar. For example, Ataulfo and Haden mangos had greater improvement in quality and sensory attributes related to fruit eating quality during ripening-softening than Tommy Atkins. In our consumer test, these quality-sensory attributes expressed during ripening that were perceived by the trained panel were also validated, supporting the need for a controlled ripening protocol in mangos.

Keywords: descriptive analysis, end ripening point, hot water-treated, *Mangifera indica* L., softening

Practical Application: This research provides information on the benefits of ripening on mango sensory attributes identified as important to improve eating quality of the fruit. With this information, postharvest handling and cultivar characteristics of mangos can be improved to increase consumer satisfaction.

Introduction

Mango (*Mangifera indica* L.) is growing in tropical and subtropical areas, such as Central and South America, Australia, Southeast Asia, Hawaii, Egypt, Israel, and South Africa, and the mango fruit has one of the highest consumption per capita in the world (Tharanathan and others 2006; FAO 2013). Among tropical fruits in world, mango production is second behind bananas reaching 30 million tons (FAO 2013) that are mainly shipped to export markets (Tharanathan and others 2006; Brecht and Yahia 2009; Yahia 2011). Approximately 32% of worldwide mango production is exported to the United States (Evans 2008; Yahia 2011; FAO 2013; National Mango Board 2014) with fruit coming mainly from Mexico, Peru, Ecuador, and Brazil.

Mango has a short harvest season and postharvest storage life due to chilling injury (Brecht and Yahia 2009), which leads to high fruit prices after seasonal peaks (Sivakumar and others 2011). The most popular export mango cultivars are "Kent," "Tommy Atkins," "Haden," and "Keitt." Less known cultivars such as "Ataulfo," "Amelie," and "Francis" are now being widely accepted all over the world (Evans 2008; FAO 2013; Singh and others 2013).

During the year, there are many mango cultivars available with different sensory attributes; some have strong aroma, intense peel coloration, and high nutritional value (Talcott and others 2005; Pino and Mesa 2006; Kim and others 2007; Othman and Mbogo 2009; Thanaraj and others 2009; Tadmor and others 2010; Mahmood and others 2012; Nassur 2013; Makani 2014). Mango cultivars with green, yellow, or orange flesh are a good source of bioactive compounds with antioxidant activity (Robles-Sánchez and others 2009), therefore, high mango consumption can benefit human health depending on the cultivar and stage of ripeness. As mangos are climacteric fruits, they are harvested firm and mature but not ripe (ready-to-eat). This means that the stage of maturity at harvest is a very important factor in final consumer quality. If the fruit is harvested with low maturity or even immature, it will not ripen properly and will not attain its characteristic color and flavor (Suwonsichon and others 2012; Nassur 2013). At the time of purchase and/or consumption, appearance and freshness are the primary quality criteria for consumers. However, subsequent purchases of ready-to-eat products depend on satisfaction with the texture, aroma and taste quality (Kays 1999; Beaulieu and

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This article was originally published online on 7 August 2015. Subsequently, formatting in Table 3 was corrected. The corrected article was published on 20 August 2015.

Journal of Food Science
A Publication of the Institute of Food Technologists

doi: 10.1111/1750-3841.12989

Baldwin 2002). Due to the vast number of cultivars available, a detailed study of how sensory differences among those cultivars at different ripeness stages might affect marketability or export potential would provide valuable information (Suwonsuchon and others 2012; Makani 2014).

A useful method to describe product sensory quality is descriptive analysis, a refined tool that can provide detailed sensory profiles of products and/or product categories (Lawless and Heymann 2010; Suwonsichon and others 2012). Despite numerous studies on the effect of harvest maturity and ripeness stage on mango quality (Beaulieu and Lea 2003; Talcott and others 2005; Kim and others 2007), the contribution of the ripeness stage on the sensory quality of mangos has not been well determined. In addition, there is no information on defining the "end point" for ideal fruit consumption quality during ripening, meaning the point at which a fruit starts to lose the required consumer quality. When mangos arrive to the export countries, fruits arrive firm at a mature stage, when the desirable sensory attributes have not yet developed, making it necessary to allow the ripening. Although mangos are normally ripened in a storage room between the ideal ripening temperatures of 20 and 22.2 °C (Yahia 2011; National Mango Board 2014), the end ripening point and ideal ripeness stage to be reached has not been clearly defined. Thus, the goal of this study was to describe the sensory quality changes of 3 mango cultivars at 3 firmness levels (ripeness stages) to define the end ripening point for each cultivar.

Materials and Methods

Fruit material

Imported, mature, hot water-treated Ataulfo, Haden, and Tommy Atkins mangos grown in Mexico were obtained from a commercial wholesaler distributor in San Francisco, Calif., U.S.A. Mangos were transported to the Postharvest Laboratory at the University of California in Davis, Calif.. On the same day, fruit with external injuries were eliminated, while the rest were presorted, using several nondestructive criteria: Da-meter (model FRM01-F, TR Turoni srl, Forli, Italy), skin color and flesh firmness by hand touch, into low, medium, and high firmness by cultivar to facilitate the firmness category selection for the descriptive analysis. Generally, we presorted a higher number of fruit than were needed within in each firmness category. These 3 ripening stages were selected using flesh firmness and chosen based on our previous data on stone fruit and kiwifruit (Crisosto and others 1997; Valero and others 2007) and our unpublished mango bruising-transportation susceptibility and respiration data.

Approximately 20 fruit per cultivar were preselected for each firmness category and placed in a controlled temperature storage room at 20 °C and >85% relative humidity to allow ripening. Depending on the cultivar, with Ataulfo taking the shortest time and Tommy Atkins the longest, and on the ripeness stage at arrival and at harvest, fruit took 4 to 10 d from the arrival date to ripen to the different firmness categories.

Fruit quality evaluation

In the morning prior to conducting the descriptive analysis, skin and flesh color, flesh firmness, soluble solids concentration (SSC), and titratable acidity (TA) were determined for each fruit used (Nassur 2013). At this point, fruits that were previously presorted at arrival were reevaluated to assure that they were correctly categorized. Ranges for each firmness category were established based on the flesh firmness measurements. When necessary, fruit was reassigned to the correct category.

Skin and flesh color were measured using a Minolta colorimeter (model CR-400, Minolta, Osaka, Japan) with an 8 mm light path aperture. The device was calibrated with Minolta standard tile CR-400 ($Y = 93.5$, $x = 0.3114$, $y = 0.3190$). Readings at 4 equidistant points ($n = 4$) around the equatorial axis of the fruit were recorded and the lightness (L^*), chroma (color saturation; C^*), and hue angle ($h°$) were automatically calculated. For each fruit, the 4 measurements of skin and 4 measurements of flesh color were averaged (Nassur 2013).

Fruit flesh firmness was measured as resistance to penetration using a portable penetrometer (Western Industrial Supply, San Francisco) with an 8-mm probe. Measurements were taken on opposite sides of the equator of each fruit after removal of an approximately 2 mm thick piece of skin with a stainless steel vegetable peeler (Padda and others 2011; Nassur 2013). Firmness was calculated as the mean of the 2 measurements for each fruit sample and expressed in Newtons (N). SSC and TA were determined from juice samples extracted by squeezing, with a hand press through 2 layers of cheese cloth, 2 longitudinal wedges, one from each side of the fruit; the juice was pooled to form a composite sample. The SSC was measured with a temperature-compensated digital refractometer (model PR 32α, Atago Co., Tokyo, Japan). TA, expressed as percentage of citric acid, was determined with an automatic titrator (model TIM 850, Radiometer Analytical SAS, Lyon, France) connected to a sample changer (model SAC80, Radiometer Analytical SAS) by titrating 4 g juice with 0.1 N NaOH to a pH of 8.2 (González-Moscoso 2013; Makani 2013; Nassur 2013).

Sensory descriptive analysis

A descriptive analysis was conducted on 3 mango cultivars (Ataulfo, Haden, and Tommy Atkins) at 3 flesh firmness levels. Twenty-one panelists (15 female), aged ranged from 19 to 52 (mean age of 30.5) who had no known allergies to mangos and who were available at the necessary times were recruited from the Univ. of California, Davis campus. All of the studies had the UC Davis Institutional Review Board approval and all panelists gave oral informed consent. Snacks were served after each session. All panelists were trained by participating in 6 1-h training sessions. The first 2 training sessions involved panel generation by consensus of descriptors using a range of mangos at various stages of ripeness and providing potential reference standards based on the panel's initial consensus (Lawless and Heymann 2010; Delgado and others 2013). In the following 2 training sessions panelists practiced the formal tasting procedure and the use of the rating scale. The last 2 sessions evaluated panelists' agreement of descriptors and reproducibility prior to formally evaluating the mangos. Fourteen attributes with corresponding reference standards were defined by the panel (Table 1). Attribute intensity was evaluated using a continuous, unstructured 10-cm line anchored by "none" and "strong" for all attributes, except firmness (low anchor: not firm, high anchor: very firm); juiciness (low anchor: no juice, high anchor: lots of juice); fibrousness (low anchor: no fibers, high anchor: many fibers); and chewiness (low anchor: 0 to 2 chews, high anchor: 15 to 20 chews).

The experiment followed a completely randomized design with 12 fruits per firmness category per cultivar, for a total of 36 fruits per cultivar. The mango samples were kept at 20 °C until they were presented to the panelists. The firmness, skin and flesh color, TA and SSC were also measured to provide a physical basis for any quality differences detected among the firmness categories. Some extra fruits were used to replace fruit that showed internal damage. For each cultivar, 3 firmness categories composed of 12 fruits each

Table 1–Sensory attributes, definitions, and reference standards used in the descriptive analysis panel to evaluate mango cultivars.

Attribute: Aroma	Definition	Reference standard
Tropical fruit	Intensity of tropical fruit aroma associated with papaya and coconut	0.5 mL Kern's mango nectar with 0.25 g of Bob's Red Mill unsweetened coconut flakes
Peach	Intensity of peach aroma	0.5 mL Kern's mango nectar with one cut piece of 2 cm cube side of Del Monte diced peaches
Citrus	Intensity of citrus fruit aroma associated with orange, lime, and lemon	200 mL Kern's mango nectar mixed with 200 mL Newman's Virgin lemonade and 15 to 30 mL squeezed lemon juice
Green	Intensity of green aroma associated with cucumber and cucurbits	0.5 mL Kern's mango nectar with half a slice (0.5 cm) of English cucumber
Pine	Intensity of the smell of pine needles	0.5 mL Kern's mango nectar with 5 pine needles
Fermented	Intensity of the smell of overripe grapes or fruit cider	Kern's mango nectar (2/3) with (1/3) pear hard cider (ACE Perry Hard Cider)
Texture		
Firmness	Flesh only: amount of force required to bite completely through the sample. Panelist instruction: Place the sample between the molars and bite evenly	1 cm cube unripe Tommy Atkins mango, firmness 60 to 80 N
Juiciness	The amount of juice or wetness released from the sample while chewing	One seedless red grape berry
Fibrousness	The amount of fibers present in the sample	0.5 cm celery slice
Chewiness	Number of chews required to prepare the samples for swallowing	Tofu cube with 2 cm sides
Taste/Flavor		
Sweet	Taste characteristic of sugar, mainly sucrose	1 mL Kern's mango nectar only used during training
Sour	Taste characteristic of citric acid	1 cm cube unripe Tommy Atkins mango, firmness 60 to 80 N
Bitter	Taste characteristic of caffeine or quinine	One slice 0.5 cm English cucumber after the middle flesh had been removed
Tropical fruit flavor	Flavor characteristic of coconut	0.5 mL Kern's mango nectar with a pinch of Bob's Red Mill unsweetened coconut flakes

were evaluated. The flesh firmness ranges used for Ataulfo were: 23.5 to 41.2 N (high), 19.6 to 21.6 N (medium), and 1.9 to 13.7 N (low). For Haden, the ranges were: 21.6 to 62.8 N (high), 19.6 to 21.6 N (medium), and 7.8 to 9.8 N (low). Finally, the ranges for Tommy Atkins were: 11.8 to 15.7 N (high), 8.8 to 9.8 N (medium), and 3.9 to 7.8 N (low). Each cultivar was evaluated on a different day (session). On the day a cultivar was evaluated, each fruit was peeled and the mango flesh cut in half along the contour of the seed. Half of the fruit was used for physiochemical analysis and the other half for sensory analysis.

Panelists evaluated the samples in isolated tasting booths under fluorescent light. Each panelist was presented 9 mango samples per session: 3 firmness categories of one cultivar with 3 replicates per category in a randomized and balanced order across panelists. Each replicate was from a different fruit to expand the narrow range provided by just one fruit, and to check each panelist's reliability. Samples were served at room temperature in 2 oz soufflé cups with lids, labeled with 3-digit random codes (Lawless and Heymann 2010). Panelists were asked to cleanse their palates with water and crackers between samples. Compusense 5 Software (Guelph, ON, Canada) (Compusense 1998) was used to generate the 3-digit codes and the randomized order presented to the panelists.

Consumer test based on firmness

Fruit selection and sorting. Kent mango fruits from Peru were obtained from Costco Wholesale in Woodland, Calif., and were preselected at the store for equal firmness by touch and freedom from disease. The fruits were transported to the Postharvest Laboratory at the University of California, Davis, and immediately sorted by touch into groups with low, medium, and high firmness. Fruits with high firmness, approximately a 3rd of the total fruits and labeled "mature," were immediately stored at 10 °C with >85% relative humidity until the day of the test. The rest of the fruits were allowed to ripen at 20 °C with >85% relative humidity for 3 to 8 d (Brecht and Yahia 2009).

Fruits were periodically tested for firmness and moved to 10 °C storage when they reached the "partially ripe" stage, defined as 18 to 26 N. Although fruits that were moved were selected by touch, subsampling with a penetrometer was conducted to more accurately detect the fruits that reached each stage. Firmness was measured by removing a 2 cm dia piece of skin with a vegetable peeler and then using a penetrometer (Western Industrial Supply, San Francisco) with an 8 mm tip to measure penetration force. Selection for the partially ripe stage continued until only half of the fruits stored at 20 °C remained, or one third of the original quantity. The remaining fruits were left to ripen to the "ripe" stage, approximately 5 to 13 N and subsequently transferred to 10 °C for storage. Stored fruit remained at 10 °C until the morning of the consumer test.

Consumer test. The day before the test, 30 fruits were selected and resorted by touch into 3 firmness categories (mature, partially ripe, ripe), with 10 fruits per category. The samples were prepared on the day of the test and placed in 2 oz soufflé cups labeled with 3-digit codes. Six samples per fruit were obtained from 3 quarter-fruit slices by cutting in half each slab longitudinally that had been cut parallel to the seed. The final fruit firmness was measured as described previously prior to cutting the fruit.

The test was carried out at the Robert Mondavi Institute at the University of California. Trays were prepared for each consumer with one sample from each of the 3 firmness categories.

Table 2–Postharvest quality attributes of 3 mango cultivars at 3 ripeness stages based on firmness.

Quality attribute	High	Medium	Low
Ataulfo			
Firmness (N)	32.35 a[a]	20.59 b	7.84 c
Dry matter (%)	22.45 b	22.23 b	23.21 a
SSC (%)	18.07 a	17.19 b	18.84 a
TA (% citric acid)	0.99 a	0.82 b	0.56 c
SSC:TA	18.25 b	22.96 b	33.64 a
pH	3.93 a	3.53 b	3.38 c
Skin L*	55.03 b	55.77 b	59.31 a
Skin chroma	36.22 c	38.15 b	41.02 a
Skin hue	96.39 a	91.68 a	89.80 a
Flesh L*	73.75 a	74.09 a	71.49 b
Flesh chroma	55.55 a	55.50 a	59.93 a
Flesh hue	92.87 a	92.91 a	91.58 b
Haden			
Firmness (N)	42.16 a[a]	20.59 b	8.82 c
Dry matter (%)	16.12 b	16.47 a	16.61 a
SSC (%)	13.34 b	14.01 a	13.87 a
TA (% citric acid)	0.63 a	0.28 b	0.10 c
SSC:TA	23.71 c	68.00 b	167.35 a
pH	3.72 c	4.33 b	5.21 a
Skin L*	59.09 a	60.17 a	57.80 a
Skin chroma	43.26 b	46.86 b	49.79 a
Skin hue	97.97 a	90.63 b	67.42 c
Flesh L*	64.48 b	69.85 a	65.62 b
Flesh chroma	62.83 b	66.00 a	65.87 a
Flesh hue	83.79 b	85.38 a	82.49 c
Tommy Atkins			
Firmness (N)	13.75 a[a]	9.31 b	5.88 c
Dry matter (%)	12.39 b	12.73 b	13.58 a
SSC (%)	10.24 b	10.36 b	19.46 a
TA (% citric acid)	0.22 a	0.17 b	0.18 b
SSC:TA	51.53 b	66.72 b	139.86 a
pH	4.36 c	4.54 a	4.46 b
Skin L*	55.59 b	55.60 b	59.53 a
Skin chroma	36.58 b	37.98 b	41.32 a
Skin hue	93.05 a	92.73 a	89.88 a
Flesh L*	73.66 a	73.97 a	71.58 b
Flesh chroma	5.93 a	55.83 a	56.71 a
Flesh hue	92.76 a	92.81 a	91.60 b

[a]Same letters within the row indicates no statistical difference ($P \geq 0.05$) between means according to Tukey's test.
**$p \geq 0.01$ and *$p \geq 0.05$, according to Tukey's test.

The experiment used a Williams design and they were presented to the consumers in a random order generated by Compusense 5 software (Compusense 1998). The trays included a scorecard on which the consumers expressed their overall liking using a 9-point hedonic scale, with 1 = dislike extremely to 9 = like extremely (Peryam and Pilgrim 1957; Delgado and others 2013; Nassur 2013) with each point labeled in between. Forty-six consumers, 70% male and 30% female, (average age 58, range 32 to 68) who had signed waivers confirming their understanding that their participation was voluntary, reported eating fresh mangos and who had no known allergies to mangos participated in the test. Consumers were instructed to sip bottled water between samples to cleanse their palate.

Consumer acceptance was measured as both degree of liking and percentage acceptance. Percentage acceptance was calculated as the number of samples that were accepted (score > 5) divided by the total number of samples evaluated within the firmness category (Delgado and others 2013). In a similar manner, the percentage of "dislike" (score < 5) and "neither like nor dislike" (score = 5) were calculated.

Statistical analysis. Data analysis was performed for each variable through an analysis of variance (ANOVA) using the SAS statistical program (SAS version 9.0, Cary, N.C., U.S.A.). The mean values of each firmness category were compared using Tukey's honestly significant difference (HSD) mean separation test ($P \leq 0.05$). The mean sensory attribute values were also subjected to principal component analysis (PCA) with the SAS program (Nassur 2013).

For the statistical analysis of the consumer test, the degree of liking data were also subjected to an ANOVA followed by a Tukey's HSD mean separation test using the RStudio program (RStudio 2013). ANOVA resulting in a P-value lower than 0.05 was considered significant, while mean scores with different mean separation letters were considered significantly different.

Results and Discussion

Mango ripeness stage and quality evaluation

There were significant differences among firmness categories for all 3 cultivars (Table 2). For Ataulfo, Haden, and Tommy Atkins, high-firmness mangos had high TA and pH and low SSC and SSC: TA ratios. These values were significantly different from the medium- and low-firmness categories. At the beginning of storage, Haden mangos were the firmest cultivar.

Among cultivars, Ataulfo was more acidic than the other cultivars, and the TA only fell to low values after the fruit was very soft. In low-firmness Ataulfo, the SSC:TA ratio was 5 and 4 times lower than for Haden and Tommy Atkins, respectively (Table 2). The TA of Tommy Atkins fruit was not different in fruit with medium

Table 3–Overall means for sensory attributes of mango cultivars at 3 ripeness stages based on firmness.

Sensory attribute	High	Medium	Low	*P* value
Ataulfo				
Aroma				
Tropical fruit	3.01 b[a]	3.05 b	4.05 a	<0.0001**
Peach	3.04 b	3.21 b	3.95 a	0.0051**
Citrus	2.17 a	1.87 a	2.17 a	0.4399
Green	1.74 a	1.43 a	1.78 a	0.2060
Pine	1.73 a	1.36 a	1.78 a	0.2827
Fermented	1.78 a	1.94 a	1.09 b	0.0771
Texture				
Firmness	4.28 a	3.34 b	2.66 c	0.0009**
Juiciness	3.21 c	3.69 b	4.22 a	<0.0001**
Fibrousness	1.43 a	0.79 b	0.95 b	<0.0001**
Chewiness	3.47 a	3.11 a	2.58 b	<0.0001**
Taste/flavor				
Sweet	3.11 b	3.52 b	4.71 a	<0.0001**
Sour	5.73 a	5.52 a	3.82 b	<0.0001**
Bitter	2.37 a	2.15 a	2.12 a	0.5489
Tropical fruit	1.52 b	1.88 b	2.86 a	<0.0001**
Haden				
Aroma				
Tropical fruit	3.10 b*	4.21 a	4.54 a	<0.0001**
Peach	3.16 b	4.18 a	4.69 a	0.0001**
Citrus	2.30 a	1.74 a	2.22 a	0.0938
Green	1.78 a	1.57 a	1.99 a	0.1833
Pine	2.01 a	2.45 a	2.35 a	0.2677
Fermented	1.83 a	2.12 a	2.25 a	0.2749
Texture				
Firmness	3.65 a	3.23 a	2.04 b	<0.0001**
Juiciness	6.24 b	6.84 a	6.72 b	0.0136*
Fibrousness	5.33 a	5.27 a	5.43 a	0.8661
Chewiness	3.47 a	3.10 a	2.18 b	<0.0001**
Taste				
Sweet	3.53 c	5.33 b	6.24 a	<0.0001**
Sour	5.63 a	2.79 b	1.45 c	<0.0001**
Bitter	1.85 a	1.02 b	0.84 b	<0.0001**
Tropical fruit	1.48 c	2.96 b	3.68 a	<0.0001**
Tommy Atkins				
Aroma				
Tropical fruit	3.07 a*	3.30 a	3.59 a	0.0981
Peach	3.37 a	3.53 a	3.83 a	0.1670
Citrus	1.73 a	1.86 a	2.24 a	0.0822
Green	1.72 a	1.77 a	1.97 a	0.3900
Pine	1.90 a	1.58 a	1.86 a	0.2827
Fermented	1.47 a	1.59 a	1.62 a	0.7370
Texture				
Firmness	3.55 a	3.74 a	2.77 b	<0.0001**
Juiciness	5.40 a	4.69 b	4.86 ab	0.0114*
Fibrousness	5.67 a	6.10 a	6.27 a	0.1253
Chewiness	3.48 ab	3.83 a	3.16 b	0.0061**
Taste/Flavor				
Sweet	3.26 b	3.74 ab	3.77 a	0.0286*
Sour	2.72 a	1.83 b	1.57 b	<0.0001**
Bitter	1.58 a	1.24 a	1.28 a	0.0897
Tropical fruit	2.04 a	1.97 a	2.24 a	0.3975

[a]Same letters within the row indicates no statistical difference ($P \geq 0.05$) between means according to Tukey's test.
$^{**}p \geq 0.01$ and $^{*}p \geq 0.05$, according to Tukey's test.

to low firmness, but in Ataulfo and Haden, the TA changed according to firmness. The SSC:TA ratio for Haden increased significantly through all 3 firmness categories. Tommy Atkins mangos had a dramatic increase in SSC, from 10.4% to 19.5%, between the medium- (9.3 N) and low- (5.9 N) firmness categories. The TA of Tommy Atkins mangos decreased with softening from high (13.7 N) to low (5.9 N) firmness. The SSC and SSC:TA ratio for Tommy Atkins were significantly greater in the low-firmness category than in the medium or high categories, which were not significantly different from each other.

It is agreed that sweetness is mainly related to sugar content, which includes sucrose, glucose, and fructose (Malundo and others 2001; Rodriguez-Plegeguezuelo and others 2012; González-Moscoso 2013). Among sugars, fructose is sweeter than sucrose, which is in turn sweeter than glucose. The 2 major pathways in plants are photosynthesis and respiration. Sugars are derived from photosynthesis while acids are generated from respiration reactions in the tricarboxylic acid cycle (Knee 2002). Changes in sweetness can be due to sugar compositional changes that should be further studied, while organic acids are the major source of sour

Table 4–Degree of liking and percentage consumer acceptance for imported Kent mangos at 3 ripeness stages based on firmness.

Cultivar	Ripening stage	Firmness (N) min	Max	Degree of linking (1 to 9 scale)[a]	Acceptance (%)	Neither like nor dislike (%)	Dislike (%)
Kent	Ripe	4.5	13.3	7.0 a[b]	87.3	0.0	12.7
	Partially ripe	15.6	26.7	7.2 a	89.2	8.1	2.7
	Mature	51.2	71.2	4.6 b	39.1	8.7	52.2
		HSD		0.97			
		P value		2.9×10^{-10}			

[a]Degree of liking: 1 = dislike extremely, 2 = dislike very much, 3 = dislike moderately, 4 = dislike slightly, 5 = neither like nor dislike, 6 = like slightly, 7 = like moderately, 8 = like very much, 9 = like extremely.
[b]Same letters within the same column indicate no significant difference between means ($P \geq 0.05$, Tukey's HSD).

taste in fruit (Da Conceicao Neta and others 2007). The observed decrease in acidity in fruit flesh during softening can explain changes in the sensory perception of sweet and sour tastes (Table 3).

Mango skin color plays an important role in the perception of overall quality by consumers (Gonzalez-Aguilar and others 2001). Skin color expressed as hue angle was significantly higher (greener) on fruit with high firmness (Table 2), following the expected changes during softening-ripening. During softening, Haden fruit became less green and more yellow. Skin color changes from green to yellow or orange during ripening is due to increased activity of the chlorophylase enzyme, which accelerates chlorophyll degradation (Lizada 1993; Pakkavatmongkol 1996). However, this typical change (green to yellow) was not observed in Ataulfo and Tommy Atkins due to their specific skin colors. Ataulfo mangos are a vivid yellow-orange, while Tommy Atkins fruits tend to have skin with a dull red blush that covers much of the fruit, with green, and orange-yellow accents (National Mango Board 2014).

Sensory descriptive analysis

Ataulfo. During softening, tropical fruit and peach aromas increased, while the fermented aroma decreased (Table 3). Perception of specific fruit aroma is determined by a diverse range and intensity of volatile compounds synthesized during ripening (Márquez and others 2011), which together produce the unique tropical fruit and peach aromas perceived in Ataulfo. This characteristic aroma is an important determinant of consumer preference and acceptance.

Ataulfo mango softening was associated with a decrease in fruit flesh fibrousness and chewiness and increased juiciness (Table 3). These texture changes are considered desirable to improve the eating quality of the fruit (Nassur 2013) suggesting that Ataulfo mangos should be ripened properly before consumption.

During ripening of climacteric fruit, flesh softening is linked to increased expression and activity of cell wall-degrading enzymes and changes in cellular turgor pressure (Oey and others 2007; Goulao and Oliveira, 2008; Nassur 2013). Breakdown of cell wall polysaccharides can reduce fibrous texture because it reduces polysaccharide chains in fruit flesh (Sane and others 2005; Goulao and Oliveira 2008). Cell wall breakdown and decreased cellular turgor during softening can reduce the force required to chew and extract water from fruit flesh. This could explain the

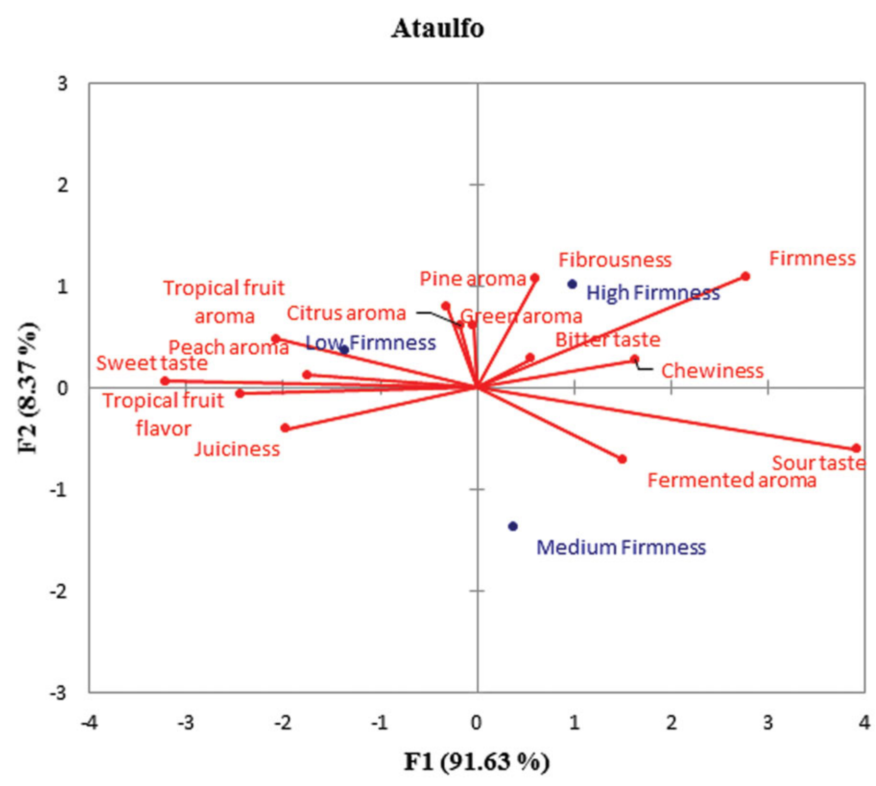

Figure 1–Principal component analysis of sensory attributes of Ataulfo mangos at 3 flesh firmness levels (high = 32.35 N; medium = 20.59 N; low = 7.84 N).

perceived lower chewiness and higher juiciness in the lowest fruit flesh firmness category.

Bitter taste, although low, did not change during ripening. However, increased sweet taste and tropical flavor; and decreased sour taste were perceived only in medium- (20.5 N) to low- (7.9 N) firmness fruits (Table 3). In Ataulfo, the change from medium to low firmness was also the point at which TA decreased (Table 2). Organic acids are the major contributors to sour taste in fruit (Da Conceicao Neta and others 2007) and reduced acidity has been proposed as a reason for increased perception of sweet taste (Malundo and others 2001; Delgado and others 2013). Therefore, the observed decreased acidity and increased SSC:TA ratio during softening could explain the perceived increase in tropical fruit flavor and sweet taste in Ataulfo mangos (Tables 2 and 3).

The data indicate that softening of Ataulfo mangos from medium (20.5 N) to low (7.9 N) firmness is accompanied by desirable changes in aroma, texture, taste, and visual appearance, improving flavor and eating quality of the fruit. In the PCA, high flesh firmness was related to sensory attributes such as firmness and fibrousness (Figure 1). Medium flesh firmness was associated with sensory attributes, such as sour taste, chewiness, fermented aroma, and tropical fruit flavor (Figure 1). Low flesh firmness was related to desirable attributes for ready-to-eat purposes, such as sweet taste and tropical fruit aroma (Figure 1). Results show that even when Ataulfo mangos reached an average flesh firmness of 7.9 N, the fruit still had quality suitable for consumption.

Haden. Like Ataulfo mangos, tropical fruit and peach aromas increased in Haden mangos during softening from high (42.1 N) to low (8.8 N) flesh firmness (Table 3). All other aroma attributes evaluated were not significantly different among the 3 flesh firmness categories (Table 3). Aroma compounds originate from several different pathways in fatty acid, amino acid, phenolic, and terpenoid metabolism (Knee 2002). As fruit ripen, characteristic aroma compounds are produced, a process often coupled with ethylene synthesis in climacteric fruit such as mangos (Schaffer and others 2007).

Panelists did not detect significant differences between the high- and medium-firmness categories for sensory fruit firmness and chewiness (Table 3), even though instrumental flesh firmness measurements were statistically different among the 3 categories (Table 2). Juiciness had the lowest value at high flesh firmness, increased at medium flesh firmness, and decreased again at the low flesh firmness (Table 3). Decreased fruit juiciness during softening can be a consequence of pectin polysaccharide metabolism, increasing its capacity to retain water and decreasing juiciness perception in fruit tissue (Brummell and others 2004). These studies also showed that further pectin polysaccharide breakdown during ripening reverses fruit juiciness, possibly due to short pectin chains that can no longer strongly retain water (Brummell and others 2004; Goulao and Oliveira 2008). Panelists detected decreased chewiness when the fruit softened from medium to low firmness, meaning that softer fruit required less force to be chewed. Fruit softening during ripening is a major quality attribute that frequently has limited shelf-life and could arise from loss of turgor, degradation of starch, or breakdown of the mango cell wall (Knee 2002).

Changes in taste/flavor attributes were more noticeable than changes in aroma attributes as fruit softened. All taste/flavor attributes evaluated had significant changes among firmness categories. The sweet taste was higher in fruit with low firmness; and the opposite was observed for bitter and sour taste. Tropical fruit flavor followed the same trend as sweet taste, with the highest value in the low firmness category. Changes in sensory attributes such as green aroma and loss of flesh firmness have been reported during mango ripening (Suwonsichon and others 2012).

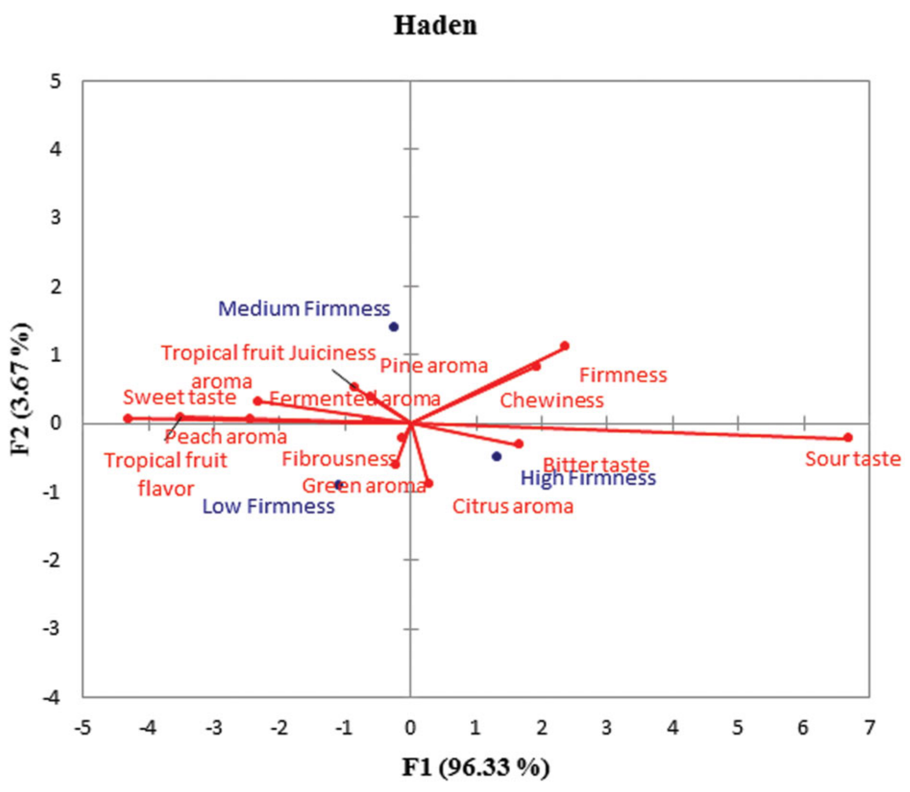

Figure 2–Principal component analysis of sensory attributes of Haden mango at 3 flesh firmness levels (high = 42.1 N ± 5.4, medium = 20.5 N ± 0.9, low = 8.82 N ± 0.1).

In the PCA analysis, high flesh firmness was related to sour taste. Medium flesh firmness was related to pine aroma and juiciness; and low flesh firmness, to tropical fruit and peach aromas and tropical fruit flavor (Figure 2). The flesh firmness of the low category (8.8 N) does not represent an "end point" for consumption of Haden mangos, since desirable characteristics were still present, while undesirable attributes such as fermented aroma were not yet perceived (Figure 2).

Tommy Atkins. No aroma attributes of Tommy Atkins mangos were significantly different among the 3 firmness categories. The texture attributes, on the other hand, showed significant differences for firmness, juiciness, and chewiness (Table 3). Low values of sensory firmness and chewiness were observed in fruit in the low firmness category, as with the other cultivars. Juiciness had the highest mean in the high flesh firmness category, but it was not statistically different from the low category. On the other hand, chewiness had the lowest mean in samples with low flesh firmness, but it was not statistically different from the high firmness category (Table 3). Panelists did not perceive any differences among the 3 firmness categories of Tommy Atkins for fibrousness (Table 3).

Sweet and sour taste varied depending on the firmness category. The panelists perceived greater sweet taste in fruits with low flesh firmness and the opposite was observed for sour taste (Table 3). The other taste/flavor attributes evaluated, bitter and tropical fruit flavor, did not differ as the firmness of the samples changed.

For all 3 cultivars and attributes, the scores ranged at the lower end of the scale (below 7). This could be attributed to the samples not having the same degree of sensory attribute intensity as the standards. In the PCA of the sensory attributes of Tommy Atkins mangos for the 3 firmness categories, samples with medium firmness (9.3 N) were positively correlated with chewiness and sweet taste (Figure 3). Green and tropical fruit aroma, fibrousness and tropical fruit flavor correlated with low flesh firmness mangos (Figure 3).

Consumer test based on firmness

The ripeness stage, measured as firmness, significantly affected degree of liking ($P < 0.001$, obtained from the ANOVA) and percent consumer acceptance of Kent mangos (Table 4). For this consumer test the firmness used ranged from 4.5 to 71.2 N (Table 4). The first 2 ranges of firmness categories were successive, 4.5 to 13.3 N (ripe) and 15.6 to 26.7 N (partially ripe), while the third range was from 51.2 to 71.2 N (mature). Although there was no significant increase in liking from partially ripe to ripe, there was a significant increase in liking from mature to partially ripe. The degree of liking increased from "neither like nor dislike" (4.6) for mature fruit to "like moderately" (7.0) for ripe mangos.

Percentage acceptance increased from 39% to 89.2% as firmness decreased from > 51.2 to < 26.7 N. The "neither like nor dislike" percentage decreased from 8.1% to 0% for partially ripe to ripe fruit, while the percentage "dislike" increased from 2.7% to 12.7%. Even though the percentage of "neither like nor dislike" only decreased slightly from mature to partially ripe, from 8.7% to 8.1%, respectively, there was a dramatic decrease in the percentage dislike, from 52.2% to 2.7%.

The information obtained from this consumer test confirms that flesh firmness between 4.5 and 26.7 N will meet consumer acceptance. Even though a consumer might prefer to eat a mango within this firmness range, it would be preferable to distribute firmer mangos to retailers to extend the display period. It is also important to point out that a wider acceptable range might be possible, since firmness between 26.7 and 51.2 N was not tested.

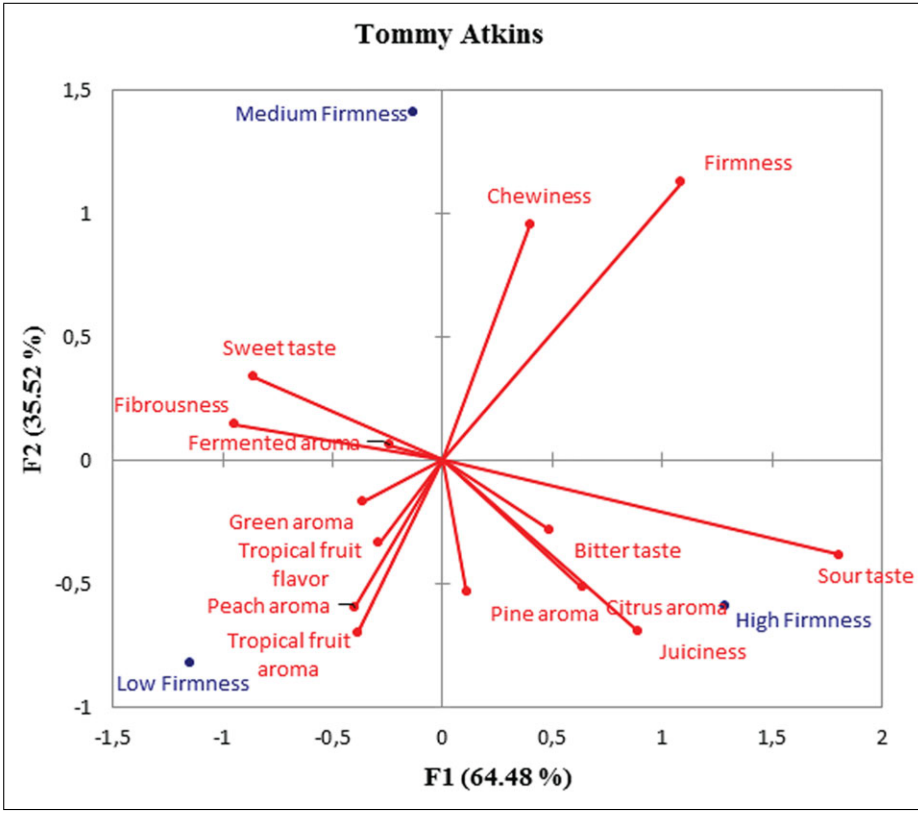

Figure 3–Principal component analysis of sensory attributes of Tommy Atkins mango at 3 flesh firmness levels (high = 13.7 N ± 0.1, medium = 9.31 N ± 0.07, low = 5.88 N ± 0.1).

Conclusions

The 3 hot water-treated mango cultivars tested were characterized by green aroma, fibrousness, and sour taste when the fruit were from the high firmness category and by sweet taste, juiciness, and tropical fruit aroma in the low firmness category. All cultivars developed desirable sensory characteristics during softening/ripening such as increased sweetness and juiciness; and decreased sourness. For Haden and Tommy Atkins mangos, the maximum expression of desirable sensory attributes occurred when these cultivars attained the ripeness stage corresponding to the medium firmness category. The same conclusions were reached with the consumer test. Ataulfo, a high-acidity mango cultivar, had to ripen until it reached the low firmness category to attain the more desirable sensory characteristics and lower acidity. This sensory study highlighted the importance of establishing a general commercial ripening protocol for mangos, with additional determination and control of the "ending point" in cultivars with high acidity such as Ataulfo, to assure maximum expression of all desirable sensory attributes and consumer acceptance.

Acknowledgments

The authors would like to acknowledge the Brazilian government (CAPES and CNPq) for supporting the senior author during her period at the Univ. of California, Davis, and the National Mango Board for funding this study.

Author Contributions

Rita de Cássia Mirela Resende Nassur—collected test data, interpreted results, drafted and reviewed the manuscript.

Sara González-Moscoso—helped in the results and the manuscript writing.

Gayle M. Crisosto—designed the study and reviewed the manuscript.

Luiz Carlos de Oliveira Lima—advisor and reviewed the manuscript.

Eduardo Valério de Barros Vilas Boas—advisor and reviewed the manuscript.

Carlos H. Crisosto—designed the study, senior advisor, interpreted the results, final review.

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