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Effect of Harvest Date on Mango (*Mangifera indica* L. Cultivar Osteen) Fruit's Qualitative Development, Shelf Life and Consumer Acceptance

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Abstract: The qualitative characteristics of mango fruits change throughout their development process and are also influenced by their duration. Harvesting at different times after the fruit set affects external and internal quality and the post-harvest behavior and management possibilities of the fruits. The objective of this study was to assess the evolution of the most important physicochemical and organoleptic parameters of cv. Osteen fruits concern the length of their stay on the plant and also to their post-harvest management. For this reason, fruits were harvested progressively in ten pickings. The study showed that mango fruits that are kept on the tree reach the best quality traits, corresponding to their physiological maturation. The length of the storage period needed to reach the consumption point varies greatly according to the harvesting moment and to the different environmental parameters, which also affect the organoleptic and physicochemical quality of the fruits. The number of days after full flowering were confirmed to be the primary information to consider when planning harvest with commercial use of the fruit, but interesting indications can be acquired through the definition of non-destructive (hardness, color) or destructive (dry matter) parameters. The data collected help improve mango fruit's post-harvest management practices, to provide a product with constant quality and homogeneity to the consumer.

Keywords: *Mangifera indica*; physicochemical analyses; sensory profile; consumption point

1. Introduction

The quality parameters of mango (*Mangifera indica* L.) fruits change daily. Being a climacteric fruit, mango is characterized by an increase of its transpiration activity after its physiological maturity stage; this is due to a process triggered by ethylene gas [1], during which the overall quality of the fruit changes substantially [2].

Mango fruits are usually harvested when they are still green and not physiologically ripe; they continue their ripening process during transportation and storage [3]. During this period, which can span over different times according to the storage methods, the fruits reach the optimal characteristics for their consumption [2,4–7].

Changes in the environmental conditions that fruits experience during their growth and storage can influence the final quality [8]. These changes happen during the ripening process and involve the variation in total soluble solids (TSS) content, pH value, carotenoid content and sugar/acid ratio [9–11]. Thus, fruit ripening on the tree and fruit ripening after harvesting reach different quality levels in a cultivar-dependent manner [12]: quality characteristics change completely depending on the time of harvesting. Therefore, it is crucial to identify the most appropriate harvesting time. As of today, there is no univocal criterion that can be used to correctly detect the ripeness degree of the fruit-based on its external aspect, and the non-destructive indices that are currently used during and after

the harvest show a low accuracy [13,14]. Such destructive indices, in fact, proved to be not representative because of the management and cultivation variability among the various orchards [15]. Among the widely used criteria for determining the mango fruit ripeness, the most sensible refers to the number of days since full flowering [16]. This, however, must be adjusted according to the productive destination and the desired characteristics the fruit must acquire [17]. The number of days required also varies depending on the geographical region and microclimatic growing conditions of the trees [2]. This can result in production batches that are heterogeneous in terms of physicochemical parameters, making the post-harvest management of the fruits more complicated [2,6,7,18].

The fruits collected early do not ripen properly and can show characteristics that make them unsuitable for consumption (abnormal color, low TSS content). On the other hand, a late harvest can determine an uneven ripening and reduce the sugar/acid ratio [19,20].

The fundamental parameter regarding the ripeness is the TSS content, which has a strong influence on the consumers' appreciation of the product [21]. Research conducted by Makani [22] showed that cv. Tommy Atkins fruits with a high TSS content (above 13.5 °Brix), were appreciated by most of the consumers, while those with a low TSS content (below 12 °Brix) were appreciated only by a small percentage. It is essential to evaluate if TSS and other chemical parameters are correlated with the dimension, shape, color and aroma of the fruits and if it is possible to detect them precisely to use them as harvest indices.

The goal of this study was to assess the evolution of the most important physicochemical parameters of cv. Osteen fruits during their on-tree development and ripening process, to understand how the number of days between full flowering and harvest affects the physicochemical quality and shelf-life of the product. We also tried to define the actual influence of the harvesting time on the organoleptic quality of the fruits at consumption, considering the differences in their post-harvest management.

2. Materials and Methods

2.1. Plant Material and Experimental Site

The trial was carried out in an experimental orchard of the Instituto Canario de Investigaciones Agrarias (ICIA), called Cueva del Polvo, in the island of Tenerife (Canary Island, Spain—28°13′4200″ N; 16°50′0100″ W). The trial was conducted on 15-year-old cv. Osteen mango trees, grafted onto Gomera 1 rootstocks and trained to a vase shape, with a plantation frame of 5 × 6 m, and cultivated following the usual cultural practices. Osteen is a mango variety native of Florida and one of the most cultivated in Europe. The average daily temperature in the field, measured by a thermopluviometric station, was 21 °C, with an average daily minimum of 18 °C and an average daily maximum of 25 °C. The relative humidity (RH) average was 70% and 155 mm annual precipitation. Based on these data and according to the Koppen classification [23], the climate of the area can be defined as "tropical dry", or according to the Papadakis classification [24] as "tropical warm" [25].

2.2. Experimental Design

The beginning of the flowering of the mango trees taken into consideration in the year of the study (2018) happened between March and April. Full flowering was determined according to the BBCH scale for mango set up by Hernández Delgado et al. [26], where it corresponds to stage 615, when the number of open flowers in the panicle is higher than 50%. The length, width, base diameter, and a number of flowers were measured in 10 fully formed flower panicles, to identify stage 615 on the BBCH scale.

The fruit development monitoring was carried out weekly on 32 fruits from two different trees (16 fruits per tree—4 fruits in each orientation—N, S, E, W). In particular, longitudinal (LD) and transverse major (TD1) and minor (TD2) diameters were measured, to define the morphological development during the period taken into consideration—from April to August. The two transverse diameters were measured to follow the evolution of the oblong shape of the cv. Osteen fruits. The diameter measuring began after the fruit set

when the fruits had a longitudinal diameter of at least 10 mm. The fruits were harvested progressively: the first day of harvesting—105 days after full flowering—was established based on the fruit growth rate, when this was <1%. Then, 18 fruits at the same degree of ripening were collected every week, until day 168 from full flowering; these were selected according to their dimensions, good quality, and absence of damages or alterations, for a total amount of ca. 200 fruits. All the fruits were analyzed for their quality parameters. These analyses were carried out at the Tropical Horticulture Laboratory of the ICIA facility. In particular, after each weekly harvest, 6 of the 18 collected fruits were analyzed on the same day. The remaining 12 fruits were stored at the fixed temperature of 20 °C and 70% Relative Humidity until they reached a hardness value between 50–60° Durofel: then, 6 of the fruits underwent the same physicochemical analyses and the other 6 were used, on the same day, to conduct a panel test to assess the organoleptic characteristics of the fruits concerning the harvest date.

2.3. Physicochemical and Color Analyses

The analysis included the morphological characterization of the fruits: the weight (g), which was measured using a digital scale with a precision of two places of two decimal units (Gibertini, Italy); the measurement of the transverse and longitudinal diameters ("1" and "2"), was performed using a digital caliper TR53307 (Turoni, Forlì, Italy).

A CIELAB colorimetry system was used to define the color, using a Minolta CR-300 Chroma Meter (Konica Minolta, Tokyo, Japan) which recorded the spectrum of reflected light and converted it into a set of color coordinates (L, a* and b* values). A Minolta standard white plate was used to standardize the instrument [1]. Color measurements were performed at three points in the equatorial region of the mango peel and pulp.

The Dry Matter content of the fruits was measured removing a portion of 27 mm width and 10 mm depth of the fruit without its peel: the dry matter was then determined as the difference between the weight of the fresh sample (ranging between 5 and 10 g) and the final weight of the sample after being kept for 7 days in an oven at 60 °C. The final weight is the value that remains constant after at least three repeated weightings of the sample.

Peel and pulp firmness were recorded with a penetrometer with an 8 mm diameter round probe for the pulp and a flat-ended probe for the peel (Turoni, Forlì, Italy). The values obtained were rescaled according to the Hedonic scale for comparison purposes [26]: 10–8 meant firm, 8–6 slightly soft, 6–4 soft, 4–2 were over soft [3].

The hardness measurements were carried out in a rapid non-destructive way, using a Durofel (CTIFL Copa Technologie, Saint Etienne du Gres, France) dynamometer with a bolt of 3 mm diameter (0.10 cm^2). This test measures the elasticity in the outer part of the fruit pulp without penetrating the fruit peel. The Durofel firmness tester was used to determine consumption points before applying destructive measures [27]. Hardness was calculated as the mean of the 3 measurements for each fruit sample and expressed on a scale from 1 (soft) to 100 (firm). Based on judgments by trained panels and consumers, consumption points corresponded to a firmness threshold of 50–60 Durofel unit.

2.4. Sensory Analyses

The sensory analyses were carried out by a semi-trained panel of 20 people [28] who evaluated the color of the peel and pulp, the presence of fibers, the aroma, the sweetness and the flavor, assigning qualitative and quantitative values. The judges evaluated the samples on a discontinuous scale, attributing to each descriptor a score ranging from "1" (absence of sensation) to "10" (maximum intensity of the descriptor). The fruits were evaluated when they reached the consumption point, after a period of storage at 20 ± 1 °C and 70% R.H. At each panel session, each judge was supplied pieces from at least three different fruits. Among the judges the order of presentation of the fruit was randomized and water was used to rinse the mouth between each tasting [28].

2.5. Data Analyses

Data analysis was carried out using XLSTAT software (Addinsoft). Grubbs' test was applied to detect outliers in the data set. The physicochemical and sensory data were tested for differences between the harvest date using the one-way analysis of variance (ANOVA; general linear model). The differences between harvest date were tested with Tukey's high significance difference (HSD) test at the 0.05 significant level.

3. Results and Discussions

The observed mango trees reached full flowering on the week between 26–31 March 2018, when all the selected inflorescences were in the same phenological stage. The flower count showed that the average of their number per panicle was 1.543, the average length of the panicle was 25.51 cm, the average width was 21.05 and the average basal diameter of 5.84 mm. Each panicle was carrying an average of 33.32 secondary branches.

A sigmoidal-type growth was highlighted as fruits diameters (longitudinal and transverse) were monitored (Figure 1). At the beginning of monitoring (during the first 50 days after full flowering) a relevant flower drop was noticed and, later, the small fruits dropped even more intensively (more than 98% of the small set fruits fell from the panicles) [29]. After this phase, each panicle was carrying 4 or 5 fruits until day 90 from full flowering; however, at the end of development the average number of fruits per panicle was between 2 and 3. Fruit diameters increased rapidly until about 80 days after full flowering and then slowed down over time, until the fruit was fully developed, following the single sigmoidal pattern that is typical for the growth of mango fruits [30]. The fruits reached their final dimension (phenological stage 800 [25]) after approximately 100 days from full flowering; however, the weight of the fruits continued its increase in the whole period under consideration.
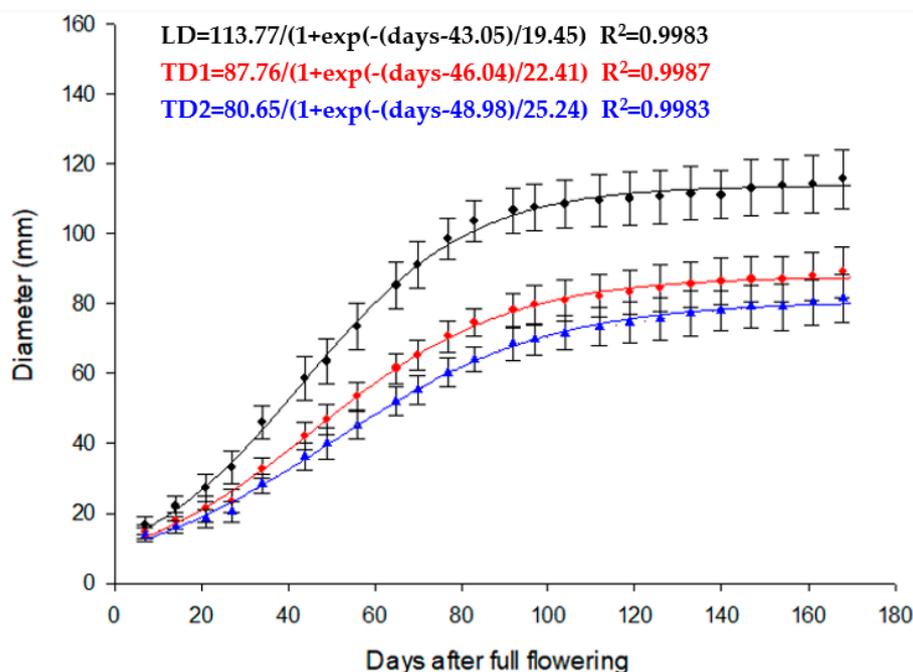

$$LD=113.77/(1+\exp(-(\text{days}-43.05)/19.45)) \quad R^2=0.9983$$
$$TD1=87.76/(1+\exp(-(\text{days}-46.04)/22.41)) \quad R^2=0.9987$$
$$TD2=80.65/(1+\exp(-(\text{days}-48.98)/25.24)) \quad R^2=0.9983$$

Figure 1. Time course of the diameters of the selected fruits (LD—Longitudinal Diameter—in black, TD1—Major Transversal Diameter—in red, TD2—Minor Transverse Diameter—in blue).

The observed mango trees reached full flowering on the week between 26–31 March 2018, when all the selected inflorescences were in the same phenological stage. The flower count showed that the average of their number per panicle was 1.543, the average length of the panicle was 25.51 cm, the average width was 21.05 and the average basal diameter of 5.84 mm. Each panicle was carrying an average of 33.32 secondary branches. The hardness

of the fruit at harvest did not vary significantly between the harvesting date (80–90° Durofel) in the samples left on the tree during the whole growth period (Table 1). Nevertheless, a slight decrease was observed at the consumption point in those fruits harvested later on, probably due to major peel dehydration. The loss of hardness of peel is due to the action of enzymes that alter the structure and composition of the cell walls [31], with partial or total solubilization of the polysaccharides, hydrolysis of starch and other polysaccharides [32]. Peel firmness values at the consumption point are inversely related to the time of storage at room temperature.

Table 1. Physicochemical parameters of Osteen mango (mean ± SD, *n* = 3) at harvest date (days after full flowering).

Harvest Date	Hardness (° Durofel)		Peel Firmness (kg/cm²)		Pulp Firmness (kg/cm²)		Dry Matter (%)	
105	86.56 ± 0.97	ns	11.82 ± 0.34	a	8.44 ± 0.31	a	11.71 ± 0.53	e
112	85.67 ± 0.84	ns	11.31 ± 0.40	a	8.03 ± 0.23	a	12.79 ± 0.46	de
119	84.67 ± 1.18	ns	10.50 ± 0.34	ab	7.88 ± 0.23	a	13.55 ± 0.46	d
126	83.06 ± 1.18	ns	9.60 ± 0.34	b	7.40 ± 0.40	ab	13.96 ± 0.46	d
133	85.22 ± 0.75	ns	9.36 ± 0.31	b	6.15 ± 0.21	b	15.09 ± 0.41	cd
140	85.64 ± 0.84	ns	8.64 ± 0.35	b	6.16 ± 0.23	b	16.03 ± 0.48	c
147	84.83 ± 0.84	ns	7.97 ± 0.34	bc	5.61 ± 0.23	c	16.34 ± 0.46	c
154	81.25 ± 0.84	ns	9.32 ± 0.35	b	5.60 ± 0.23	c	16.11 ± 0.46	bc
161	82.17 ± 1.02	ns	7.64 ± 0.40	c	4.89 ± 0.31	cd	17.34 ± 0.46	b
168	82.91 ± 0.84	ns	8.14 ± 0.45	bc	3.80 ± 0.23	d	19.01 ± 0.50	a

The values followed by different letters in the same column indicate significant differences (Tukey test, $p < 0.05$; ns = not significant).

At the consumption point, the fruits showed firmness values below 1.5 kg/cm² (Table 2) [33]. The change in this parameter after the fruit was harvested is of utmost importance to define ripening protocols for the fruits themselves, to obtain ready-to-eat products, which have an increasingly stronger demand on the market [34].

Table 2. Physicochemical parameters of Osteen mango (mean ± SD, *n* = 3) at consumption point after period of storage at 20 °C and 70% RH (harvest date + shelf life).

Harvest Date + Storage Period (days)	Hardness (° Durofel)		Peel Firmness (kg/cm²)		Pulp Firmness (kg/cm²)		Dry Matter (%)	
105 + 28	54.90 ± 1.60	ns	1.61 ± 0.16	ns	0.60 ± 0.05	ns	10.38 ± 0.55	e
112 + 27	53.47 ± 2.27	ns	1.30 ± 0.23	ns	0.62 ± 0.07	ns	11.80 ± 0.77	d
119 + 21	53.73 ± 2.27	ns	1.49 ± 0.23	ns	0.58 ± 0.07	ns	13.24 ± 0.77	c
126 + 20	57.53 ± 2.27	ns	1.87 ± 0.23	ns	0.65 ± 0.07	ns	14.17 ± 0.77	bc
133 + 20	55.57 ± 1.60	ns	1.52 ± 0.18	ns	0.73 ± 0.05	ns	15.43 ± 0.60	b
140 + 16	56.63 ± 1.60	ns	2.33 ± 0.21	ns	0.92 ± 0.05	ns	16.19 ± 0.55	b
147 + 16	58.33 ± 2.07	ns	1.99 ± 0.28	ns	0.98 ± 0.07	ns	15.39 ± 0.77	b
154 + 15	57.79 ± 1.79	ns	2.03 ± 0.21	ns	0.65 ± 0.05	ns	17.75 ± 0.60	ab
161 + 14	59.78 ± 2.07	ns	2.53 ± 0.25	ns	0.50 ± 0.07	ns	16.50 ± 0.77	b
168 + 12	58.89 ± 2.07	ns	2.13 ± 0.28	ns	0.50 ± 0.07	ns	19.44 ± 0.77	a

The values followed by different letters in the same column indicate significant differences (Tukey test, $p < 0.05$; ns = not significant).

Dry Matter (DM) is a very important quality index, as it is linked to the carbohydrate content in the fruit, which are the compounds that have the biggest influence on the typical taste of mango [35]. The Dry Matter content of the fruits can be monitored and used as an indicator of the appropriate harvest moment for mango [36], which generally correspond to values around 15% DM content [37]. Various authors [38,39] found a better overall sensory quality in mango fruits with smaller water content. In our study, the Dry Matter content of the fruits varied significantly from values of 11.5% to 21% with the harvesting

moment. The changes in all the mentioned parameters are the key factor to enact the best post-harvest practices and estimate the final quality of the fruit [40].

Color is the parameter whose change is the most noticeable during the development of the fruit both on the plant and after the harvest and is often indicated as a fundamental criterion for consumer's choice [41]. However, it is not an appropriate index of mango fruits' ripeness, because color differs significantly within varieties [2] and not all varieties change their peel color during ripening [42]. Moreover, the external color of the fruits can vary because of external factors such as exposure to sunlight and harvesting time. In the Osteen cv, fruits we found relevant peel and pulp color variations during both pre-harvest (Table 3) and post-harvest (Table 4) periods. When the on-tree growth rate of the fruit decreases, the most noticeable change in the fruit's color is the diminishment of the percentage of green, as confirmed by the shift of the parameter a* towards the red frequencies (+a*), due to an increase in the carotenoids content [3], responsible for the chromatic change of the peel of the fruit towards red-orange tone. We observed a significant variation in the values of a* from 4.1 to 13.2.

Table 3. Peel and pulp color of Osteen mango (mean $\pm$ SD, *n* = 12) at harvest date (days after full flowering). L indicates the color's brightness, a* its position between red/magenta and green and b* its position between yellow and blue.

Harvest Date	L Peel		a* Peel		b* Peel		L Pulp		a* Pulp		b* Pulp	
105	40.5 $\pm$ 1.0	ns	4.1 $\pm$ 1.7	b	15.7 $\pm$ 1.8	b	77.1 $\pm$ 0.8	ns	−11.9 $\pm$ 0.4	e	30.3 $\pm$ 1.1	d
112	41.3 $\pm$ 1.2	ns	6.2 $\pm$ 2.0	ab	16.3 $\pm$ 2.0	b	78.3 $\pm$ 0.9	ns	−9.9 $\pm$ 0.5	d	31.4 $\pm$ 1.4	d
119	41.4 $\pm$ 1.2	ns	8.3 $\pm$ 1.8	ab	13.4 $\pm$ 1.9	b	79.0 $\pm$ 0.9	ns	−7.8 $\pm$ 0.5	c	36.4 $\pm$ 1.5	cd
126	40.0 $\pm$ 1.2	ns	11.0 $\pm$ 2.0	ab	12.4 $\pm$ 1.9	b	80.4 $\pm$ 0.9	ns	−7.6 $\pm$ 0.5	cd	42.2 $\pm$ 1.4	bc
133	41.1 $\pm$ 1.1	ns	9.9 $\pm$ 2.1	ab	15.0 $\pm$ 1.7	b	80.5 $\pm$ 0.8	ns	−5.5 $\pm$ 0.5	bc	39.2 $\pm$ 1.3	c
140	38.1 $\pm$ 1.2	ns	11.7 $\pm$ 1.9	ab	12.8 $\pm$ 1.9	b	78.9 $\pm$ 0.9	ns	−4.5 $\pm$ 0.5	bc	48.0 $\pm$ 1.4	bc
147	41.5 $\pm$ 1.2	ns	11.7 $\pm$ 2.1	ab	17.4 $\pm$ 1.9	ab	78.5 $\pm$ 0.9	ns	−4.2 $\pm$ 0.6	b	48.7 $\pm$ 1.5	ab
154	41.7 $\pm$ 1.2	ns	10.0 $\pm$ 2.2	ab	19.3 $\pm$ 1.9	a	80.4 $\pm$ 0.9	ns	−4.6 $\pm$ 0.5	bc	47.2 $\pm$ 1.4	ab
161	44.0 $\pm$ 1.2	ns	11.6 $\pm$ 1.9	ab	23.4 $\pm$ 1.9	a	77.0 $\pm$ 1.0	ns	−2.6 $\pm$ 0.5	ab	48.8 $\pm$ 1.4	a
168	43.1 $\pm$ 1.2	ns	13.2 $\pm$ 2.2	a	20.2 $\pm$ 1.9	a	77.8 $\pm$ 0.9	ns	−1.8 $\pm$ 0.6	a	50.9 $\pm$ 1.8	a

The values followed by different letters in the same column indicate significant differences ($p \leq 0.05$).

Table 4. Peel and pulp color of Osteen mango (mean $\pm$ SD, *n* = 12) at consumption point after storage period at 20 °C and 70% RH (harvest date + shelf life). L indicates the color's brightness, a* its position between red/magenta and green and b* its position between yellow and blue.

Harvest Date + Storage Period (days)	L Peel		a* Peel		b* Peel		L Pulp		a* Pulp		b* Pulp	
105 + 28	52.6 $\pm$ 1.6	ns	23.5 $\pm$ 3.1	ns	42.6 $\pm$ 2.2	a	64.1 $\pm$ 1.2	ns	15.0 $\pm$ 0.6	a	66.8 $\pm$ 1.4	ns
112 + 27	49.1 $\pm$ 2.2	ns	26.8 $\pm$ 4.4	ns	38.0 $\pm$ 3.1	ab	62.0 $\pm$ 1.7	ns	15.1 $\pm$ 0.9	a	64.3 $\pm$ 2.0	ns
119 + 21	49.3 $\pm$ 2.2	ns	25.9 $\pm$ 4.4	ns	38.9 $\pm$ 3.4	ab	64.7 $\pm$ 1.7	ns	10.5 $\pm$ 0.9	b	67.9 $\pm$ 2.0	ns
126 + 20	45.9 $\pm$ 2.2	ns	20.9 $\pm$ 4.4	ns	29.7 $\pm$ 3.1	b	65.6 $\pm$ 1.7	ns	8.9 $\pm$ 0.9	bc	64.5 $\pm$ 2.0	ns
133 + 20	45.2 $\pm$ 1.7	ns	20.6 $\pm$ 3.3	ns	25.4 $\pm$ 2.3	b	63.1 $\pm$ 1.3	ns	6.4 $\pm$ 0.7	c	60.4 $\pm$ 1.5	ns
140 + 16	46.6 $\pm$ 1.6	ns	12.3 $\pm$ 3.1	ns	25.0 $\pm$ 2.2	b	63.9 $\pm$ 1.2	ns	4.2 $\pm$ 0.6	d	57.7 $\pm$ 1.4	ns
147 + 16	48.5 $\pm$ 2.2	ns	7.1 $\pm$ 4.4	ns	28.0 $\pm$ 3.1	b	65.6 $\pm$ 1.7	ns	4.4 $\pm$ 0.9	d	61.7 $\pm$ 2.0	ns
154 + 15	47.7 $\pm$ 1.7	ns	17.5 $\pm$ 3.4	ns	27.9 $\pm$ 2.7	b	64.4 $\pm$ 1.3	ns	5.1 $\pm$ 0.7	d	61.9 $\pm$ 1.6	ns
161 + 14	47.2 $\pm$ 2.2	ns	22.2 $\pm$ 4.4	ns	24.5 $\pm$ 3.4	b	67.8 $\pm$ 1.7	ns	4.7 $\pm$ 0.9	d	57.9 $\pm$ 2.2	ns
168 + 12	47.1 $\pm$ 2.2	ns	26.4 $\pm$ 4.4	ns	27.4 $\pm$ 3.4	b	66.7 $\pm$ 1.7	ns	4.3 $\pm$ 0.9	d	62.0 $\pm$ 2.0	ns

The values followed by different letters in the same column indicate significant differences ($p \leq 0.05$).

Many consumers prefer mangos with a change of color in their peel because they link it to the characteristic taste and flavor of the well-ripe fruit [43]. The parameters L* and b* do not show substantial changes during this phase. During the growth phase, pulp a* and b* parameters also undergo a variation, increasing their values linearly towards yellow (+b*) and red (+a*) tones. The color of the pulp went from a bright yellow to a more orange tone in the late-harvested fruits (in particular a* values go from −11.9 to −1.8 and b* values go from 30.3 to 50.9). During the fruit's ripening, it is possible to notice a diminishment in

the brightness (L*) and an increase, compared to the harvesting moment, in the parameters a* and b* of the fruit's peel, consumption point gains its typical orange to red color, which makes the fruit more appealing to the consumers [8]. On the other hand, the fruit's pulp shows a notable variation in its values for the parameter a*, which decrease from 15.0 to 4.3 until the consumption point is reached.

The sensory analysis was carried out when the fruits reached the consumption point (50–60 Durofel). The fruits harvested earliest (105 and 112 days from full flowering) had worse scores than those left on the tree longer. This can be explained by the lower TSSC (<12° brix) and DM (<12%) values of these samples at consumption point, due to an abnormal or uneven ripening. On the other hand, 80% of the panelists evaluated as "very good" or "excellent" (with ratings higher than 8.5 out of 10.0) all the fruits tested in the different harvesting moments later than day 119 from full flowering.

The destructive analysis, which was performed in the harvested fruits every 7 days starting after 105 days from full flowering (earliest record of commercial maturity on the fruits), showed, as expected, an increase in TSS content from 6.8 at the beginning to 9.7° Brix at the end of the harvest period; this was due to the approaching of the fruit to the full maturity (Table 5). Thus, it is possible to state that a longer stay on the tree leads to an exponential growth of the TSS content, even in the span of few weeks. Furthermore, De Lucena et al. [42] found an increase in the TSS content in Tommy Atkins cv. fruits from 5.6 °Brix on day 35 from anthesis to 8.5° Brix on day 112 while Lederman et al. [44] pointed out an increase in the same variety from 7.5° Brix on day 95 from full flowering to 10.9 on day 125. The TSS content is one of the parameters of greatest interest in the ripening process, as a sweeter fruit is more appealing to consumers [45]. The analyzed data show how the °brix increases linearly in the fruits which are left on the tree, reaching at full maturity a value of 10.0° brix. The fruits harvested on the same day reach values of 18° brix at the consumption point after they were stored for a period of 20 °C. The length of the storage period varies according to the harvest date (Figure 2). The fruits harvested on day 105 from full flowering showed an average TSS content value of 6.8° brix at harvest and an average value of around 10° brix after a storage period of 28 days at 20 °C. Instead, as was mentioned before, fruits that were harvested later needed a shorter time to achieve an even higher increase in TSS content. Correlating the fruit's dimensional growth parameters and its physicochemical quality at harvest has an important practical value because growers can quantify the best moment for harvesting with the product's commercial use without needing to perform destructive analyses. The determination of the exact number of post-harvest 20 °C storage days, based on the fruit's non-destructive quality parameters after harvest, such as hardness, can lead to important indications for optimal placement of the fruits on the market and can be used as an index of quality in other cultivars.

The titratable acidity, expressed as percentage of citric acid, varies according to the ripeness degree at the harvest moment and plays an important role in the final taste and flavor of the fruit, which are strongly influenced by its sugar/acid ratio [41]. In particular, the samplings carried out in our experiment showed that TA decreases from 1.12% on day 105 from full flowering to 0.35% on day 168, while at consumption point significant differences were not observed (0.11% ± 0.01) within the samples. Therefore, this parameter undergoes a drastic reduction during the ripening process, as observed by Wongmetha [46], as the citric, ascorbic and malic acids are used as a substrate for the fruit respiratory processes [47]. The same author pointed out the slight increase in the pH values during the fruit development that was also observed in our study (from 3.49 to 3.93 at different harvest dates). For all harvest dates, at consumption point, pH values were higher than at harvest.
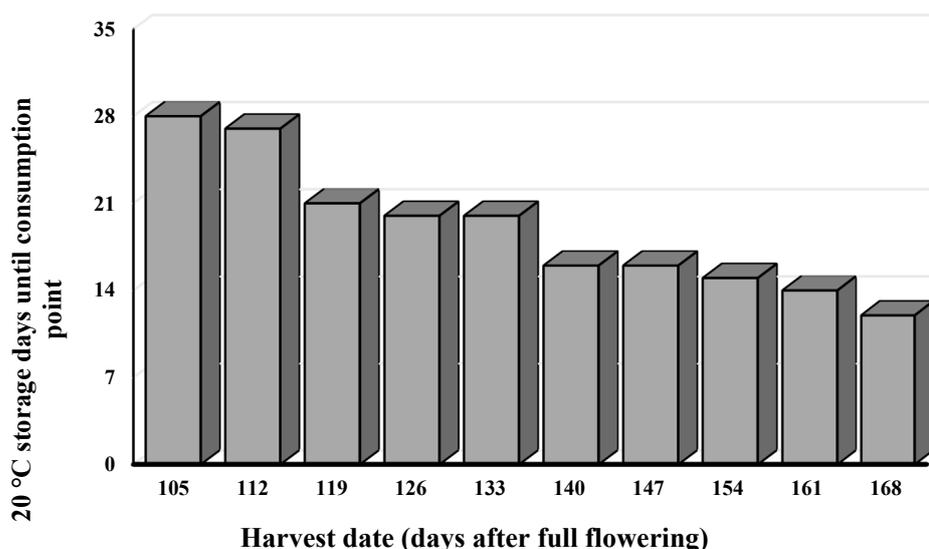
Figure 2. Number of storage days at 20 °C until fruit reaches consumption point in relation to the harvesting moment (expressed in days from full flowering).

Table 5. Evolution of pH, Titratable Acidity (TA) and Total solids soluble content (TSS) at harvest (days from full bloom) and at consumption point.

Harvest Date	At Harvest			Harvest Date + Storage Period (Days)	At Consumption Point		
	pH	TA	TSS °Brix		pH	TA	TSS °Brix
105	3.49 ± 0.02 c	1.12 ± 0.03 a	6.80 ± 0.17 d	105 + 28	5.23 ± 0.05 a	0.08 ± 0.00 ns	10.43 ± 0.36 f
112	3.42 ± 0.03 c	1.07 ± 0.06 a	6.98 ± 0.20 cd	112 + 27	5.20 ± 0.02 a	0.09 ± 0.00 ns	11.72 ± 0.51 ef
119	3.74 ± 0.07 b	0.85 ± 0.04 b	6.93 ± 0.20 cd	119 + 21	5.19 ± 0.07 a	0.07 ± 0.01 ns	13.11 ± 0.51 de
126	3.61 ± 0.03 b	0.76 ± 0.02 b	7.20 ± 0.29 c	126 + 20	4.58 ± 0.03 c	0.12 ± 0.00 ns	13.43 ± 0.51 d
133	3.74 ± 0.01 b	0.59 ± 0.09 c	7.68 ± 0.18 bc	133 + 20	5.10 ± 0.16 a	0.11 ± 0.03 ns	14.85 ± 0.45 c
140	3.76 ± 0.02 b	0.55 ± 0.03 c	8.18 ± 0.20 b	140 + 16	4.93 ± 0.06 ab	0.12 ± 0.01 ns	15.14 ± 0.40 c
147	3.88 ± 0.08 a	0.52 ± 0.06 c	9.30 ± 0.20 a	147 + 16	4.75 ± 0.07 b	0.15 ± 0.04 ns	13.70 ± 0.51 c
154	3.91 ± 0.02 a	0.48 ± 0.06 c	9.35 ± 0.25 a	154 + 15	4.88 ± 0.09 ab	0.13 ± 0.01 ns	15.96 ± 0.40 ab
161	3.97 ± 0.04 a	0.37 ± 0.04 d	9.37 ± 0.29 a	161 + 14	4.95 ± 0.05 ab	0.12 ± 0.01 ns	15.72 ± 0.51 b
168	3.94 ± 0.05 a	0.33 ± 0.02 d	9.73 ± 0.20 a	168 + 12	4.92 ± 0.04 ab	0.14 ± 0.02 ns	17.50 ± 0.51 a

The values followed by different letters in the same column indicate significant differences (Tukey test, $p < 0.05$; ns = not significant).

4. Conclusions

The qualitative characteristics of mango, cv. Osteen, fruits varied throughout their development process even after the fruits reached their final dimensions, in relation to the length of their stay on the plant and also to their post-harvest management. The study showed that mango fruits that are kept on the tree reach the best quality traits, corresponding to their physiological maturation. In fact, the length of the storage period needed to reach the consumption point varies greatly according to the harvesting moment and to the different environmental parameters, which also affect the organoleptic and physicochemical quality of the fruits.

The analysis highlighted how the firmness and consistency of the fruits at harvest stay similar regardless of the harvest date, but they decrease with different speeds, in relation to the harvest date, after a period of storage (Figure 3). However, the panel test judges did not highlight noticeable differences in the fruits that had been harvested 119 days after full flowering and onwards which were then evaluated at the consumption point. Detecting a precise harvesting time is of the utmost importance, as this strongly affects the fruit's further maturation process and its subsequent shelf-life.
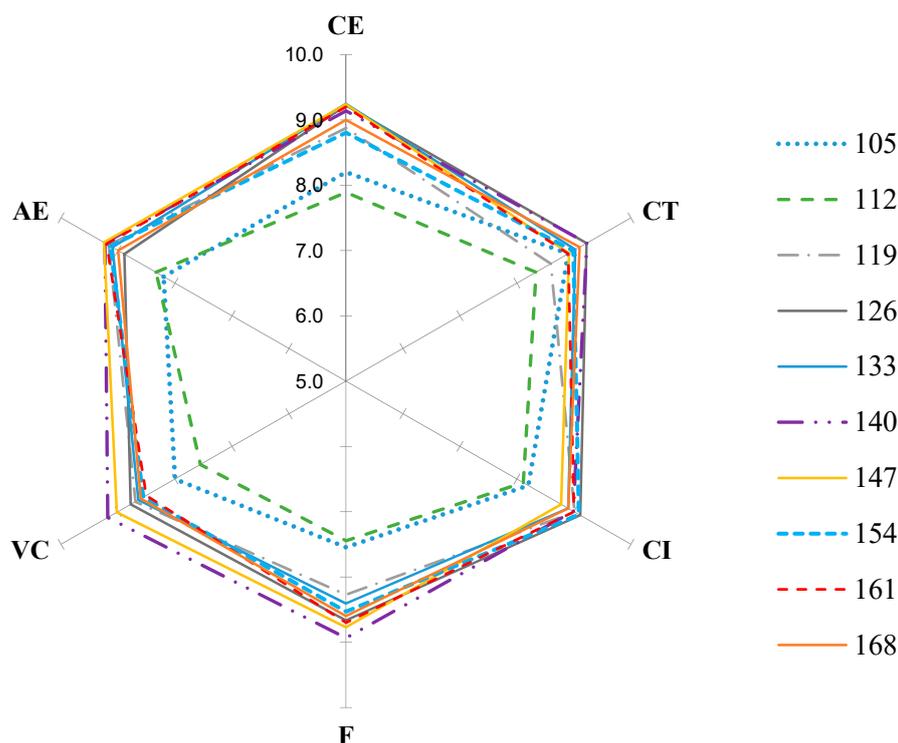
Figure 3. Sensory profile at consumption point, in relation to the harvest date (Days from full flowering). CE = Peel color; CT = Tactile firmness; CI = Pulp color; F = Flavor; VC = Overall evaluation; AE = Overall appearance.

The data collected in this study confirm that the number of days from full flowering, that is the length of the fruit's stay on the tree, is primary information to consider when deciding the harvest moment of the fruit, depending on its planned commercial use. Our results showed that from 126 to 133 days from full flowering there was a more noticeable consumer acceptability. This corresponds to higher DM values of 14–15%.

This information on the fruit's behavior based on its harvest date can, therefore, help improve the product's post-harvest management practices, to provide a product with constant quality and homogeneity to the consumer.

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