Article

Quality and shelf life of three physiological states of fruits of avocado variety Lonjas

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Abstract

The native fruits of *Persea americana* Mill. var. Drymifolia are generally consumed and marketed locally, their quality attributes and recommended physiological state of harvest have been little studied. The objective of this research was to evaluate quality parameters such as firmness, weight loss and color of fruits of 'Lonjas' avocado harvested in three physiological states of maturity (green, changing and black) to compare which of them retains the best parameters when reaching consumption maturity. The fruits were harvested in Tacámbaro, Michoacán in 2019, the variables evaluated the day after the harvest were: length, diameter, thickness of the epicarp, weight of the epicarp, mesocarp and seed, the fruits were stored at 22 ±2 °C, the loss of weight, firmness and color of the fruit until maturity of consumption were evaluated every two days. On the other hand, the refrigeration effect (13 ±2 °C) of fruits in changing state was evaluated. Fruits in the changing physiological state presented the largest dimension, as well as the highest pulp and seed content. Of the fruits stored at 22 ±2 °C, the green physiological state had less weight loss. Nevertheless, when reaching consumption maturity, the three physiological states presented similar values of firmness and color of the epicarp. In the changing physiological state, the values related to the color of the mesocarp stood out. The time of harvest depends on the quality parameter in which there is the greatest interest. Refrigeration is recommended to extend the shelf life.

Keywords: *Persea americana* Mill. var. Drymifolia, maturation, physiological state.

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Introduction

Mexico is the center of origin of *Persea americana* Mill., has an abundant reserve of avocado plant genetic resources, López *et al*. (2012). Located mainly from central Mexico to Central America, Álvarez *et al*. (2018). According to data from SIAP, materials classified as landrace are present in 21 states, with the five main states being: Nayarit, Yucatán, Puebla, Morelos and Guerrero (SIAP, 2023). The fruits of *Persea americana* var. Drymifolia can be found in ellipsoid, obovoid or pyriform shape Acosta *et al*. (2013), they have been consumed in an ancestral way, are part of the culture and ethnobotanical knowledge of the Mexican peoples (Corrales and Méndez, 2020).

Native avocados are mainly used as rootstocks for ‘Hass’ avocado, they are a source of genes of resistance to pests and pathogens, for this and other cultivars, according to Rincón *et al*. (2011), which allows for low plant production costs; however, it generates a wide genetic, phenological, productive and adaptation variation (Herrera *et al*., 2013). The native Mexican avocado is being replaced by commercial cultivars or becoming lost due to the destruction of ecosystems (Rincón *et al*., 2011).

In the municipality of Tacámbaro, Michoacán, there is a high natural genetic variability of native avocado, however, the evaluation of wild genotypes and promising selections, as well as their organoleptic and biochemical characteristics, is scarce. Some studies report that of the fruits of native avocados considered outstanding for their size, color, flavor and production are: ‘Lonjas’, ‘Vargas’, ‘Zarcoli’, ‘Zarcolín’ and ‘Rodo’, Roldán *et al*. (1999), of them, it has been possible to produce ‘Vargas’, ‘Rodo’ and ‘Lonjas’ and they have remain in the taste of Mexicans, although they do not have the importance that ‘Hass’ avocado has achieved, Barragán (1999), since the relevance of native avocados as food has been underestimated (Ramos *et al*., 2021). Regarding the native avocado ‘Lonjas’, Reyes *et al*. (2009) describes its characteristics as a tree of open habit, intermediate vigor; the young leaves have an anise smell, and it has a red hue at the beginning of its growth.

It is considered a native avocado of common use, whose potential is fresh consumption, the fruits of black color at maturity measure about 13 cm in length and 6 cm in diameter, in addition to having thin skin (epicarp). It is necessary to disseminate the horticultural, nutraceutical and agro-industrial potential of native avocados among producers, sellers and consumers, in order to value and conserve them (Corrales and Méndez, 2020). In this research, quality parameters such as firmness, weight loss and color of fruits of avocado variety Lonjas, harvested in three physiological states of maturity (green, changing and black), were evaluated to compare which of them retains the best quality parameters when reaching consumption maturity.

Materials and methods

The fruits of ‘Lonjas’ avocado, a local variety, were harvested on July 10, 2019, from 25-year-old trees, in an orchard with conventional management in the municipality of Tacámbaro, Michoacán, in three physiological states of maturity: green (the fruit showed 75% green coloration on its surface), changing (the fruit presented black coloration in 60-75% of the surface) and black (when 100% of this coloration was reached on its surface). The research was conducted in the postharvest laboratory of the College of Postgraduates. The fruits were stored at room temperature and relative humidity of 22 ±2 °C and 60 ±5%, respectively.

Evaluations were performed every two days, until each physiological state reached consumption maturity (day 4). Due to the scarcity of fruits, only the fruits that presented a changing physiological state were evaluated under refrigeration treatment (13 °C) for 9 days, then stored at 22 ±2 °C and evaluations were made at the exit from the cold treatment and two days later at a temperature of 22 ±2 °C.

Response variables

For each physiological state, six fruits were evaluated in three experimental units (two fruits per experimental unit) and the following measurements were made: percentage of dry matter (% DM), length (cm), diameter (cm), thickness of the epicarp (mm), weight of the epicarp (g), of the mesocarp (g), of seed (g) and mesocarp-seed ratio (%).

Weight loss

The weight of the fruits was recorded with an ALSEP EY-2200 digital scale, until the fruits reached consumption maturity. The percentage of weight loss was calculated according to equation 1. Percentage of weight loss= $\frac{\text{Initial weight-final weight}}{\text{Initial weight}} \times 100$ 1).

Firmness

It was determined with a texture meter (Wagner Force Five model FDV30) with conical tip of 7 mm in diameter, the measurements were made every two days. Values were reported in Newton (N).

Fruit color

The color change was determined in the epicarp and mesocarp, using a HunterLab reflection colorimeter (Reston Virginia model D25-PC2) with a D65 lighting system and an observer angle of 2°, with the values obtained (L, a and b), the luminosity (L), °Hue (equation 2) and chroma (equation 3) were calculated, every two days until the fruits reached consumption maturity (Lancaster *et al*., 1997). $\text{Hue}=\tan^{-1}$ 2). $\text{Chroma}=\sqrt{(a^2+b^2)}$ 3).

Shelf life

Shelf life was established considering the number of days in which the fruits of each physiological state reached consumption maturity, without presenting physical damage or contamination by microorganisms.

Ethylene and CO_2 concentration

These variables were only determined in avocado fruits in the changing physiological state, evaluations were made daily by means of a gas chromatograph (Perkin Elmer Clarus) according to the headspace method Tovar *et al*. (2011), a random sample of 6 fruits was taken, with which three experimental units (repetitions) of two fruits each were established, which were placed in 2 L containers hermetically closed for 1 h.

A 1 ml sample of the gas was taken from the headspace and injected into a gas chromatograph (Perkin Elmer Clarus), with a TG-Bond Q 30 m x 0.32 mm x 10 µ column of Thermo Fisher Scientific, which was simultaneously connected to a flame ionization detector (FID) and a thermal conductivity detector (TCD). The operating conditions were: column temperature 150 °C, FID 180 °C and TCD 180 °C, a standard of CO_2 with 498.6 µl mol^{-1} and of ethylene with 100 µl mol^{-1}, both of INFRA®, was used. Respiration data were reported as ml CO_2 kg^{-1} h^{-1} and ethylene concentration in µl C_2H_4 kg^{-1} h^{-1}.

Experimental design

For the analysis of data, in fruits stored at 22 °C, three repetitions (two fruits as an experimental unit) were considered, and the split plot model was applied, the evaluation of the physiological states corresponds to the large plot and the evaluation days to the small plot, an analysis of variance was performed, and the means were compared with Tukey's test ($p\leq 0.05$). The statistical program SAS® System Version 9 for Microsoft® Windows® was used.

Results and discussion

The fruits of 'Lonjas' avocado was harvested with a percentage of dry matter that varied according to the physiological state (21.2% Green, 21.7% Changing and 24.3% Black), this in accordance with the standard NMX-FF-016-SCFI-2016, which indicates that 21% DM is the minimum acceptable for the authorization of cutting and processing (Table 1). According to Corrales and Méndez (2020), avocado fruits are botanically classified as berries. The main physical characteristics that make an avocado cultivar attractive to consumers are the size and shape of the fruit, medium-sized fruits with pyriform or ovoid appearance are usually preferred, López *et al*. (2012), fruits of 'Lonjas' avocado measured from 11.1 to 12.2 cm in length and from 5.4 to 6.2 cm in diameter (Tukey's test, $p\leq 0.05$).

Table 1. Physical characteristics of fruits of 'Lonjas' avocado in three physiological states of maturity (green, changing, black).

Characteristic	Physiological stage of maturity		
	Green	Changing	Black
Dry matter (%)	21.2 ±0.6 b	21.7 ±0.5 b	24.3 ±1.4 a
Length (cm)	11.4 ±0.7 b	12.2 ±0.4 a	11.1 ±0.5 b
Diameter (cm)	5.6 ±0.2 b	6.2 ±0.3 a	5.4 ±0.2 b
Epicarp thickness (mm)	0.23 ±0.1 b	0.27 ±0.1 ab	0.3 ±0 a
Epicarp weight (g)	5.8 ±0.5 c	8.9 ±1.3 b	11.3 ±0.9 a
Mesocarp weight (g)	132.8 ±7.9 b	155.2 ±12.3 a	118.9 ±7.1 c
Seed weight (g)	41.0 ±2.1 b	49.1 ±4.1 a	40.3 ±7.8 b
Mesocarp-Seed (%)	76.4 - 23.6 a	76 - 24 a	74.7 -25.3 a

Values with different letters in a row are statistically different (Tukey; $p\leq 0.05$).

In the changing state (Table 1), were the largest fruits: 12.2 cm in length and 6.2 cm in diameter, regarding these evaluations, Acosta *et al*. (2013) reported, in avocados identified as 'Anita' and 'Salazareño', values of 10.9 and 10 cm in polar dimensions, while for equatorial dimensions 3.5

and 3.8 cm, respectively. The fruits of native avocados have great potential for their nutraceutical and agro-industrial qualities (Corrales and Méndez, 2020), they could be used by producers, food and pharmaceutical industries for different uses, of which not enough information has been reported.

It is known that the fruits of local varieties are marketed and consumed more locally, in this aspect, the consumption of the fruits can be not only of the pulp, but also of the peel (epicarp), because the peel does not compromise its organoleptic properties, on the contrary, in some cases it favors the flavor, unlike the 'Hass' avocado, which has a much thicker peel, which is not consumed (Ramos *et al*., 2021).

Regarding the characteristics of the epicarp, of the fruits of 'Lonjas' avocado, the results showed a thickness of epicarp in the green physiological state of 0.23 mm, in the changing 0.27 mm and in the black 0.3 mm (Table 1). In comparison with avocado fruits identified as 'CA-1' by Ramos *et al*. (2021), the epicarp was exceptionally thin and similar to that of grape peels, 0.24 - 0.33 mm.

In the fruits of 'Lonjas' avocado (Table 1) there was a significant difference between the three physiological states, the highest weight of the epicarp occurred in the black physiological state (11.3 g) and of the mesocarp (155.2 g) in the changing state, for the case of seed weight, the changing state obtained the highest value (49.1 g), presenting significant difference with respect to green and black, compared with other results, the weight of epicarp was similar to 'Temax-1' (10.9 g), of pulp to 'Jalea 10' (134.2 g) and 'Plat-16' (141.4 g), while in the case of seed, to those identified as 'Jalea 9', 'Temax-3', 'Jalea 10' and 'Temax 5' reported by Damián *et al*. (2017), on the other hand, Acosta *et al*. (2013) obtained values of 156.9 g of mesocarp in fruits of avocado identified as 'Anita' and 45.5 g of seed in fruits of 'Santos' avocado (similar to 'Lonjas' in black state).

According to Ramos *et al*. (2021), the weight of the parts of the fruit followed the order of: pulp> seed> peel. With regard to the mesocarp-seed ratio (Table 1) no statistically significant difference was observed, however, the fruits in green state presented higher pulp content (76.4-23.6%), followed by changing (76.0-24.0%) and black (74.7 -25.3%)). Maturation is defined as the set of external, flavor and texture changes that a fruit experiences when it completes its growth. This phase includes processes such as the coloration of the pericarp, increase in the concentration of sugars, loss of firmness, along with other physical and chemical changes. The maturation process varies according to the fruits (Azcón and Talón, 2013).

Weight loss

Authors such as Magaña *et al*. (2013) mention that the weight loss of fruits is associated with water loss, when fruits are harvested and exposed to room temperature for several days, this loss may also depend on the intrinsic and extrinsic characteristics of the product, which could be related to the vapour pressure deficit between its surface and the atmosphere in which they are. The weight loss of the fruit during the initial stages of maturation influences the maturation time, incidence and severity of ripe rots (Dixon *et al*., 2022).

Of the three physiological states evaluated, the fruits in black physiological state, Figure 1, presented higher percentage of weight loss (8.10%) when reaching consumption maturity (day 4), while Herrera *et al*. (2017) reported weight losses of 8.3% for 'Hass' avocados and 6.6% for cv. Mendez stored at room temperature.

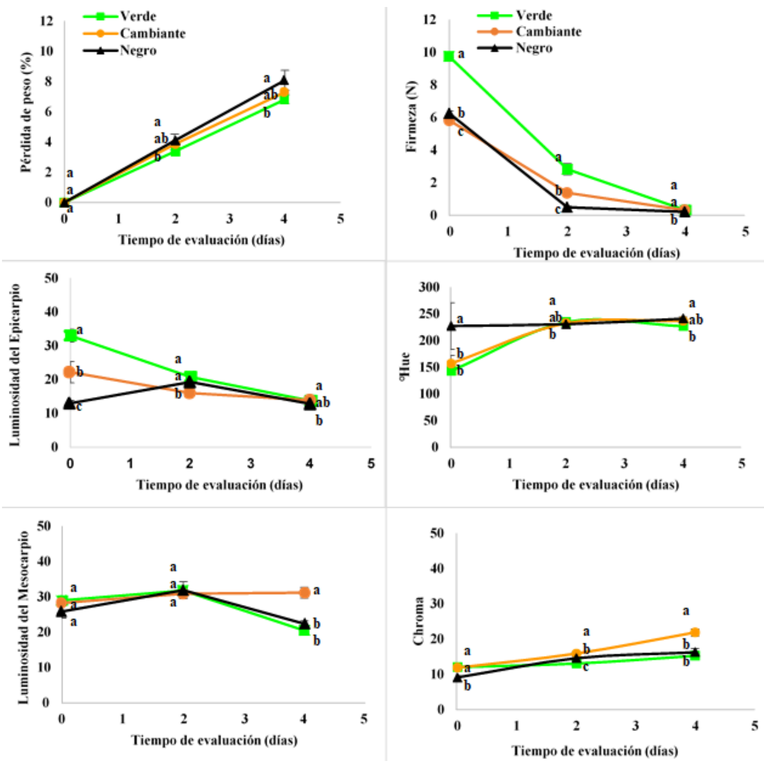

Figure 1. **Quality variables during the maturation of fruits of 'Lonjas' avocado harvested in three physiological states (green, changing and black).** Values with different letters on each evaluation day (0, 2 and 4) are statistically different (Tukey; $p\leq 0.05$).

Firmness

A proper prediction of firmness in avocado fruits is important, since it provides indirect access to the levels of maturity, fruit quality and probable storage time, the fruits are harvested green and hard to the touch; however, they soften. The rate of softening is moderate at first, increases later and stops at maturity (Mishra *et al*., 2021).

As expected, the firmness decreased, Figure 1, as time passed and as the fruit matured, the green state presented the greatest firmness (9.6 N) on day 0 of its evaluation, followed by the black and changing physiological state (6.3, 5.9N); nevertheless, on day 4, the fruits in green and changing state presented slightly higher values than black (0.32 N), Rámos *et al*. (2021) reported firmness values below 5 N (1.3-2.7 N) in fruits identified as 'CA-1' and 'CA-4' but higher than those presented in fruits of 'Lonjas' avocado, this quality attribute has been reported very little in native materials.

Fruit color

When L^* y °Hue decrease significantly, the green coloration decreases and the skin turns black, then, maturation occurs regularly, and the fruits reach consumption maturity. In fruits of ‘Méndez’ and ‘Hass’ avocado, the fruits reached consumption maturity between 8 and 12 days after harvest (Herrera *et al*., 2017).

In the fruits of ‘Lonjas’ avocado, the luminosity of the epicarp on day 4 (consumption maturity) presented the lowest values (Figure 1) with respect to days 0 and 2, for the green physiological state a value of 13.7 was reported, for changing 13.9 and for black 12.8, in the same way, values of 26.9 and 29.7 in L for external color were reported in fruits identified as ‘CA-1’ and ‘CA3’ in fruits stored at 25 °C (Ramos *et al*., 2021).

The peel of the fruits of native avocados generally presents colors with hues ranging from purple to dark due to the presence of anthocyanins, pigments with high antioxidant activity (Ramos *et al*., 2021). In evaluations of Hue, which externally indicates the dark coloration, there were higher values in the changing and black state (236.9, 241.3) of ‘Lonjas’ fruits.

The pulp has a consistency very characteristic of avocado fruits, similar to butter due to its high lipid content (up to 23% of the total weight of the pulp) and the color has yellowish hues in the center and greenish on the outside (Corrales and Méndez, 2020). The luminosity of the pulp was found in the ranges of 20 to 30, obtaining the highest values on day 2, in the case of the green and black physiological states (31.8 and 31.9), Ramos *et al*. (2021) reported L values in pulp between 55.0 and 61.72 for native fruits; in the case of chroma in ‘Lonjas’ avocado, the values increased until reaching the fourth day, with the changing physiological state being the one who presented the highest value on day 4 (21.9).

Considering that day 4 is when the fruits reached consumption maturity, it can be observed (Figure 1), that in the firmness parameter, the green state (0.32 N) is significantly different from black (0.22 N), in % of weight loss the black state (8.1%) is significantly different from the green state (6.83%), in luminosity of the epicarp the changing state (13.9) is significantly different from black (12.8), in Hue the black state (236.9 Hue) is significantly different from green (227.1 Hue), while for chroma, changing (21.9) is significantly different from green and black (15.3 and 16.3).

The results Table 2, show how fruits in different physiological states influence shelf life, with lower weight losses in the green physiological state and higher values of luminosity of the mesocarp and chroma in the black physiological state.

Table 2. Quality variables by physiological state in fruits of ‘Lonjas’ avocado at zero, two and four days of harvest.

Physiological State	Day	Firmness (N)	Weight Loss (%)	Epicarp (L)	Epicarp (°Hue)	Mesocarp (L)	Mesocarp (Chroma)
Green	0	9.7a	0 c	33 a	142.9 b	28.9 b	12.1 b
	2	2.8 b	3.3 b	20.7 b	227.1 a	31.8 a	13 b
	4	0.3 c	6.8 a	13.7 c	235.1 a	20.4 c	15.3 a

Physiological State	Day	Firmness (N)	Weight Loss (%)	Epicarp (L)	Epicarp (°Hue)	Mesocarp (L)	Mesocarp (Chroma)
Changing	0	5.8 a	0 c	22.2 a	156.8 b	28.3 b	11.8 c
	2	1.3 b	3.8 b	16 b	233.1 a	30.9 a	15.9 b
	4	0.3 c	7.3 a	13.9 b	236.9 a	31.2 a	21.9 a
Black	0	6.2 a	0 c	13 b	227.2 a	25.9 b	9.1 b
	2	0.5 b	4.1 b	19.3 a	230.8 a	31.8 a	14.6 a
	4	0.2 c	8.1 a	12.8 b	241.3 a	22.4 b	16.4 a

Values by column with different letter in each physiological state: green, changing and black, are statistically different (Tukey; $p \leq 0.05$).

Ethylene and CO_2 in fruits with changing physiological state

In climacteric fruits such as avocado, respiration increases very quickly, coinciding with increases in ethylene production, which stimulates the maturation and development of organoleptic characteristics (Azcón and Talón, 2013). The highest concentration of ethylene in fruits stored at 22 °C (Figure 2) occurred on days 2 and 3 (87.8, 92.8 µl C_2H_4 kg^{-1} h^{-1}), while for the case of CO_2, on day 3 (84.4, ml CO_2 kg^{-1} h^{-1}).

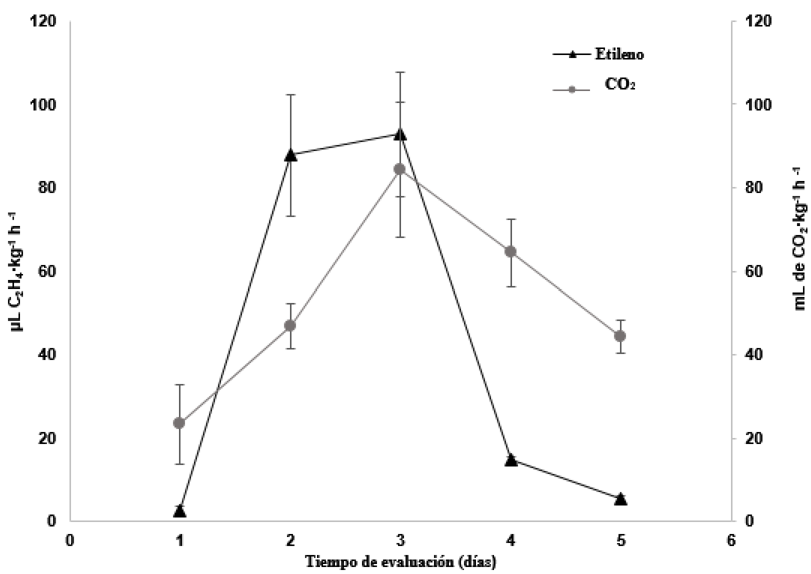

Figure 2. Respiratory intensity and ethylene production in fruits of 'Lonjas' avocado in changing physiological state, stored at 22 ±2 °C.

So far there are no reports regarding changes in ethylene and CO_2 concentration throughout maturation in native materials, nevertheless, in 'Hass' and 'Méndez' avocados evaluated by Herrera *et al*. (2017), stored at room temperature, the climacteric was reached from 7 to 8 d after harvest (harvested fruits with higher dry matter presented greater ethylene production and greater respiration speed), obtaining values of 10-100 µl C_2H_4 kg^{-1} h^{-1} and 10-50 ml CO_2 kg^{-1} h^{-1} in relation to the dry matter content.

Shelf life

The fruits of ‘Lonjas’ avocado in the states: green, changing and black had a shelf life of 4 days. On the other hand, due to the refrigeration treatment used in ‘Lonjas’ fruits in changing physiological state, the fruits reached a shelf life of up to 11 days; since the fruits were stored for 9 days at 13 °C, then stored at 22 °C and reached consumption maturity after 2 days. These results coincide with those reported by Acosta *et al*. (2013), who mention that the shelf life of native avocado fruits varies from 10.3 to 11 days and that low values ranging from 4 to 6.3 days can also be found.

Quality of fruits stored at 13 °C

Storage temperature in Hass avocado has greater influence on weight loss and firmness (Benítez *et al*., 2021), as well as on the change in color (Osuna *et al*., 2017). The higher the maturation temperature, the shorter the time to reach consumption maturity. At a storage temperature of 6 °C, color and firmness are maintained at acceptable levels, without external damage and with five days of shelf life after storage (Osuna *et al*., 2017). At 7 °C for 20 days combined with maturation at 20 °C for 6 days, fruits with homogeneous maturation, less internal damage and acceptable weight loss can be obtained (Benítez *et al*., 2021).

The fruits of ‘Lonjas’ avocado in changing state evaluated at the exit from the refrigeration treatment presented firmness values of 0.7 ±0.1 N, percentage of weight loss of 3.4 ±0.1%, luminosity and chroma in epicarp of 33.8 ±1.2 and 11.9 ±0.5 respectively, as well as luminosity and Hue in mesocarp of 17.3 ±0.6 and 204.5 ±33.2, the values were different from those obtained when reaching consumption maturity (two days after their exist from refrigeration and storage at 22 °C), firmness 0.3 ±0.1 N, percentage of weight loss of 7.7 ±0.1%, luminosity and chroma in epicarp with values of 39.5 ±1.6 and 7.7 ±0.1, as well as luminosity and Hue in mesocarp of 13.8 ±0 and 247.7 ±4.6, respectively.

Concentration of ethylene and CO_2 in fruits stored at 13 °C

There is currently not enough research describing changes in ethylene and CO_2 concentration in native avocado fruits, as reported by Osuna *et al*. (2017). Avocado is a climacteric fruit with a high respiration rate (80 to 300 mg CO_2 kg^{-1} h^{-1} at 20 °C) and high ethylene production (>100 µl C_2H_4 kg^{-1} h^{-1} at 20 °C), making it difficult to preserve and market to distant markets. One of the most common techniques to prolong shelf life and maintain avocado fruit quality is the use of refrigeration. The avocado is a fruit sensitive to cold damage when subjected to low temperatures for prolonged times.

The main symptoms of cold damage manifest as faint brown to dark brown zones in the mesocarp (Román *et al*., 2002). The principle for using refrigeration is that it slows down the physiological processes that lead to fruit maturation (Osuna *et al*., 2017), in this sense and in relation to respiration and ethylene production, the fruits in changing state stored for 9 days at 13 °C presented, at their exit, concentrations of 74.64 ±12.67 µl C_2H_4 kg^{-1} h^{-1} and 49.33 ±5.21 ml CO_2 kg^{-1} h^{-1}, one day after their storage at 22 °C values of 33.09 ±2.99 µl C_2H_4 kg^{-1} h^{-1} and 46.98 ±3.36 ml CO_2 kg^{-1} h^{-1}. When reaching consumption maturity, the presence of ethylene and CO_2 was minimally quantifiable, so these values are not reported.

Conclusions

The fruits in changing state presented the largest dimensions in length and diameter, as well as the highest content of pulp and seed, during the days of storage at 22 ±2 °C, the fruits in green physiological state had less weight loss. However, when reaching consumption maturity, the three physiological states presented similar values of firmness, luminosity of the epicarp and degrees Hue. In the changing physiological state, the values of luminosity of the mesocarp and chroma stood out.

The time of harvest depends on the quality parameter in which there is the greatest interest. Refrigeration is recommended to extend the shelf life of the fruits. The fruits of ‘Lonjas’ avocado have physiological and quality characteristics that can be considered as an alternative of production and commercialization at a more than local level. Even so, it is recommended to conduct nutritional and nutraceutical quality studies.

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