FRUITS 72(2), 74–81 | ISSN 0248-1294 print, 1625-967X online | https://doi.org/10.17660/th.2017/72.2.2 | © ISHS 2017

Original article

Fruit growth, maturation, and shelf life of two cultivars of tejocote (*Crataegus mexicana* Moc. & Sessé)

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Summary

Introduction – **Tejocote (*Crataegus mexicana*) is an important fruit crop in Mexico given its demand both fresh and processed. Its production is based on various genotypes, which implies heterogeneity in fruit production and quality. Based on studies on tree development, fructification, and fruit size, two cultivars were selected, 'Quetzalli' and 'Atlatex'; however, the changes to understand the pre- and postharvest behavior of their fruits are unknown. The objective was to evaluate some of the changes associated with the growth, maturity, and shelf life of these two cultivars.** *Materials and methods* – **To study the growth of 'Quetzalli' and 'Atlatex' tejocote fruits, small fruits were randomly labeled after fruit set and periodically measured for fresh mass, polar and equatorial diameters, as well as respiration, total sugar content, titratable acidity and pH. At the end of the growth period, a sample was collected and stored at 20±2 °C for 8 days, periodically measured for respiration, total and reducing sugar contents, titratable acidity, pH and external color.** *Results and discussion* – **The fruit growth showed a double sigmoid pattern with noticeable differences between the two cultivars. Fruit maturation began at the end of the growth period, when respiration, total sugar content, and pH increased and the malic acid content decreased. During storage, no changes were registered in respiration or the evaluated chemical characteristics, defining a non-climacteric behavior.** *Conclusion* – **At the end of the 8 days of storage, the fruits showed high weight loss (13%), a decrease in color luminosity, yellowing, and an appearance of becoming old, which characterize the marketable quality. Further studies are needed on the knowledge of both the plant physiology during fruit growth and the use of advanced technologies to preserve the fresh weight of these fruits during storage.**

Keywords
Mexico, tejocote, *Crataegus mexicana*, growth pattern, respiration rate, total sugars, fruit quality

Significance of this study

What is already known on this subject?

- Tejocote is a native fruit tree of Mexico with diverse materials identified and rustic characteristics in production.

What are the new findings?

- Diverse bioactive compounds have been determined in different organs of the tejocote plant. Their nutraceutical and medicinal properties need to be further studied.

What is the expected impact on horticulture?

- Applying genetic improvement studies by conventional and molecular techniques in this species shall reduce the native material heterogeneity and improve the antioxidant and nutraceutical capacity of the fruit.

Résumé

Croissance, mûrissement et conservation des fruits de deux cultivars de l'aubépine du Mexique (*Crataegus mexicana* Moc. et Sessé).

Introduction – **L'aubépine du Mexique (*Crataegus mexicana*) est une espèce fruitière appréciée au Mexique tant pour le marché du frais que pour les débouchés de produits transformés. La production repose sur différents génotypes, ce qui rend hétérogènes la récolte et la qualité des fruits. Sur la base d'études du développement de l'arbre, de la mise à fruit et la dimension des fruits, deux cultivars ont été sélectionnés: 'Quetzalli' et 'Atlatex'. On connait encore peu les changements de comportement opérés avant et après la récolte des fruits. L'objectif de cette étude était d'évaluer certains des changements associés à la croissance, au mûrissement et à la durée de conservation de ces deux cultivars.** *Matériel et méthodes* – **Pour étudier la croissance des fruits de 'Quetzalli' et 'Atlatex', les fruits encore petits ont été étiquetés de façon aléatoire après la mise à fruit et nous avons mesuré périodiquement leur masse fraîche, leurs diamètres polaire et équatorial, ainsi que la respiration, la teneur totale en sucres, l'acidité titrable et le pH. A la fin de la période de croissance, un échantillon a été prélevé et stocké à 20 ± 2 °C**

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pendant 8 jours, sur lequel ont été périodiquement mesurés la respiration, les teneurs en sucres totaux et réducteurs, l'acidité titrable, le pH et la couleur externe. *Résultats et discussion* **– La croissance des fruits s'est présentée sous la forme d'une double sigmoïde, avec des différences notables entre les deux cultivars. La maturation des fruits a commencé à la fin de la période de croissance, lorsque la respiration, la teneur totale en sucres et le pH ont augmenté et que la teneur en acide malique a diminué. Pendant le stockage, aucun changement n'a été noté dans la respiration ou les caractéristiques chimiques évaluées, définissant ainsi un comportement non-climactérique.** *Conclusion* **– L'étude des deux cultivars d'aubépine du Mexique a mis en évidence des différences de croissance du fruit, ce qui nécessitera d'autres études plus approfondies du métabolisme complet de la plante. À la fin de la période de stockage (8 jours), les fruits ont montré une dépréciation de leur qualité commerciale. Cette caractérisation préliminaire était nécessaire pour envisager des technologies pertinentes visant à préserver la qualité de ces fruits après leur récolte.**

Mots-clés
Mexique, aubépine du Mexique, *Crataegus mexicana*, courbe de croissance, intensité de respiration, qualité des fruits, gestion post-récolte

Introduction

Given the diversity in climates and soils, there are several fruit species being grown in Mexico, both native and introduced, with potential for use fresh and processed. The species *Crataegus mexicana* Mocino & Sessé, commonly known as tejocote, has been used since pre-Hispanic times, being closely related with the traditional Mexican traditions (Leszczyska-Borys and Borys, 2004). The fruits are eaten fresh and processed as compote, jelly, marmalade, and liquor (Nieto-Ángel, 2007). Also, the fruits have a high content of pectins with low molecular weight (Higareda *et al.*, 1995) and phenolic compounds with medicinal and antioxidant potential (Banderas-Tarabay *et al.*, 2015). The root is also credited for having diuretic effects (Özcan *et al.*, 2005; Peschel *et al.*, 2008).

Given the rustic characteristics of the plant, tejocote is grown under extreme conditions of compacted, rocky soils with limited fertility and low humidity, which allows it to contribute to soil preservation by decreasing erosion problems. These characteristics allow the tejocote to be considered as an acceptable species in the reforestation of hillsides, gullies, and semiarid zones (Nieto-Ángel and Borys, 1993). Moreover, the trees can be used as rootstock for graft propagation of tejocote and other species of quince and pear (Nieto-Ángel and Borys, 1999).

The tejocote production in Mexico was estimated to 4,399 t in 2014 (SIAP, 2015), mainly of native genotypes with minimal application of technology for growing and harvesting fruit with both heterogeneous maturity and size. This, together with the high sensibility of the fruit to mechanical damage and accelerated wilting, fosters the commercialization of low-quality fruit with a short shelf life. Nevertheless, they still garner a high demand and high prices in certain traditional times of the year. Production also has problems with fruit flies (*Rhagoletis pomonella* Walsh), traps being used as a preventive control method (Muiz-Reyes *et al.*, 2014).

Through the identification in the main producing zones in Mexico of outstanding native materials, the experimental orchard of the Universidad Autonoma Chapingo, Mexico, has an *ex situ* germplasm bank established with 163 tejocote accessions (3 trees per accession) and grafted on rootstock. These have been studied for production characteristics, fructification, and technology requirements for growing; fruit behavior pre- and postharvest is still to be studied. Therefore, the objective of the present research was to evaluate some of the changes associated with fruit growth, maturity, and shelf life of the cvs. Quetzalli and Atlatex, which in turn will help to define the pre- and postharvest physiological behavior of this fruit crop.

Materials and methods

Description of the experiment

The study was done on fruits from the 2015 production cycle of two outstanding productive tejocote cultivars, registered as 'Quetzalli' and 'Atlatex' (SNICS, 2012), both in 8-year-old trees from the *ex situ* germplasm bank of the Universidad Autonoma Chapingo, Mexico, located at 19°29'32.69"N, 98°53'20.36"W, at an altitude of 2,240 m a.s.l. The prevailing weather is temperate with a mean temperature in the warmest month (May) of 17.5 °C and in the coldest month (January) of 11.6 °C, and a mean annual precipitation of 644.8 mm, with summer rains (around 96 days).

Growth determination

The growth pattern was determined based on size increase (equatorial and polar diameter) and fresh mass of the fruits. To do this, the flowering period was identified and, 15 days after fruit set (DAS), 150 fruits per cultivar were randomly labeled in three trees. From these, eight fruits were harvested every 15 days and individually measured. They were measured for polar diameter (mm) and equatorial diameter (mm) with a digital vernier (Mitutoyo CD-6"CD, Illinois, USA), and fresh mass (g) with a digital scale (Alsep Model EY-2200A, Tokyo, Japan). The variables were measured continuously until the changes were minimal. With the registered data, the accumulated growth curves were obtained, and to determine the change kinetics through time, the mathematical function proposed by Fanizza and Colonna (1996) was applied (equation 1), as it can describe double sigmoid fruit growth patterns.

$$y = \frac{m_1}{1+e^{-m_2(x-m_3)}} + \frac{m_4}{1+e^{-m_5(x-m_6)}} \quad (1)$$

where m_1 represents the accumulated growth (g or mm), m_2 is the maximum growth rate (g day^{-1} or mm day^{-1}) in the first sigmoid curve, m_4 and m_5 represent the accumulated growth and maximum growth rate in the second sigmoid curve, m_3 and m_6 represent the days where the growth rate is at maximum in the first and second sigmoid curves, respectively. The adjustment of equation (1) to the kinetic data was done using the GraphPad PRISM® software (GraphPad Software, Inc., San Diego, CA, USA). The goodness of fit was assessed with the correlation coefficient (R^2) and root-mean-square error (*RMSE*), described by the equations (2) and (3), respectively:

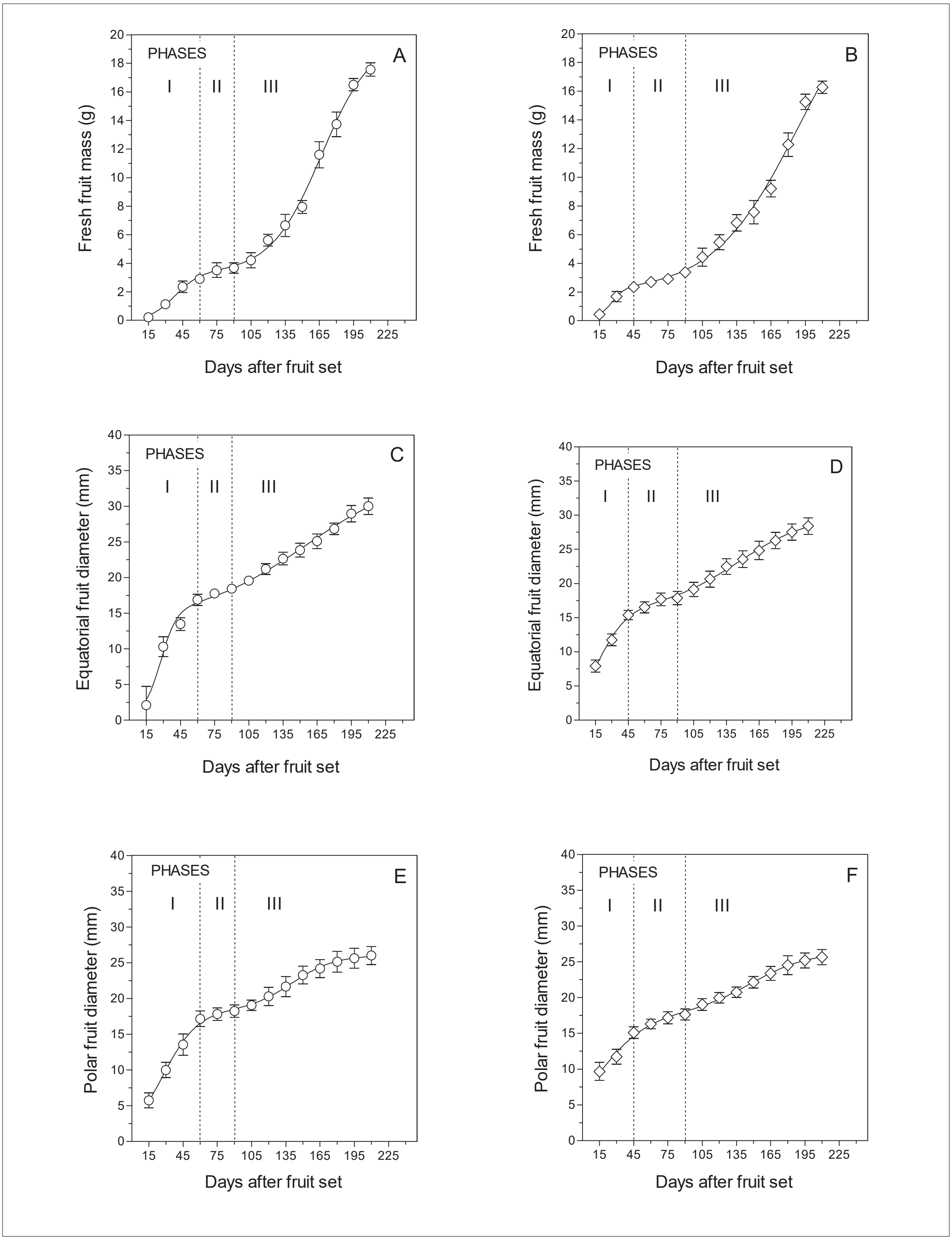

Figure 1. Changes in fresh fruit mass (g), equatorial and polar diameters (mm) of two tejocote cultivars (○) 'Quetzalli', (◊) Atlatex'. Data are mean values ± standard deviations ($n = 8$).

$$R^2 = \left(1 - \frac{SS_{reg}}{SS_{tot}}\right) \quad (2)$$

$$RMSE = \sqrt{\frac{SS_{res}}{df}} \quad (3)$$

where SS_{reg} is the sum of the squares in the regression, SS_{tot} is the total sum of the squares, SS_{res} is the sum of the residual squares, and *df* is the degree of freedom that refer to the number of data minus the number of parameters of the model.

Starting from 75 DAS, besides the growth samples, a further sample of nine fruits was harvested on the same dates. From this sample, three replicates with three fruits each were established to measure respiration rate in the whole fruit. At 90 DAS, they were also used to determine total sugars content, pH, and titratable acidity in the pulp.

Determination of respiration

The respiration rate was quantified by applying the static method described by Salveit (1993). To do this, three previously weighed fruits were placed into each of three 0.226 L containers. The containers were hermetically sealed for one hour. Subsequently, a 1 mL sample was taken with a gas syringe; the sample was injected into a gas chromatograph (Hewlett Packard, Model 5890, Wilmington, USA). The operation conditions were as follows: Helium as carrier gas (20 mL min^{-1} flow), thermal conductivity detector (TDC) temperatures of injector and oven of 170, 150, and 80 °C, respectively. The data were reported in mL CO_2 kg^{-1} h^{-1}.

Total sugar extraction and quantification

The total sugar contents (g g^{-1}) were quantified using the anthrone method (Witham *et al.*, 1971). For sugar extraction, the fruits were cut into small pieces (pulp and peel), 1 g was weighed and placed in a glass jar where 60 mL 80% ethanol (v/v) was added. The sample was boiled for 10 min and then filtered; 20 mL was taken and stored at 4 °C. After 8 days, 1 mL was taken and placed in a precipitation flask and left to evaporate at 60 °C. The residue was immediately dissolved in 20 mL distilled water. Subsequently, 1 mL of this solution was placed in a flat bottomed test tube and adjusted to 3 mL with distilled water. Then, keeping the test tube in ice, 6 mL of 0.4% anthrone solution (0.4 g anthrone in 100 mL of 98.8% sulfuric acid) was added. After this, the test tube was placed in boiling water and absorbance was measured with a spectrophotometer (Spectronic 20, Milton Roy) at 600 nm, using a 3 mL distilled water and 6 mL of 0.4% anthrone mixture as blank. The total sugar content was calculated using a standard glucose curve.

pH and titratable acidity

Titratable acidity and pH were determined according to the methodology described by the AOAC (1990). Ten grams of tejocote fruit were weighed and 50 mL water were added; this was homogenized in a blender (Mod. 6644-13, Osterizer). The malic acid content (%) was quantified through NaOH 0.1N titration of a 5-mL sample. The pH was measured using a pH-meter (Mod. 12, Corning, NY, USA).

Postharvest evaluation

Once the fruit growth became minimal, 50 fruits were randomly harvested from three trees of each cultivar and stored at room temperature (20 ± 2 °C and 50-60% relative humidity) for eight days. The following variables were evaluated every other day: respiration rate, loss of mass, and external color in whole fruits. The respiration rate (mL CO_2 kg^{-1} h^{-1}) was measured using the previously described static method (Salveit, 1993); three replicates of three fruits were done for each cultivar. Using a 9-fruit sample, weight was measured individually and loss of mass (%) was measured through the difference with initial weight. The external color was evaluated in the same way with the 9-fruit sample and individually using the CIE L*a*b* system, obtaining the data with a D-25 PC2 (Hunter Lab, VA, USA) reflection colorimeter. L* represents the luminosity of the samples (0 = black to 100 = white), and the a* and b* values indicate the variation in hue from green to red (-60 to +60) and from blue to yellow (-60 to +60), respectively (Pinheiro *et al.*, 2013). With the a* and b* values, the hue angle (°*h= arctg b/a*) and chroma [$(C= a^2 + b^2)^{½}$] were calculated (McGuire, 1992).

The total sugar and reducing sugar contents, titratable acidity, and pH of the fruit pulp were determined at the beginning and at the end of the storage period (0 and 8 days, resp.) on a sample of three fruits with three replicates. The analyses of total sugars (g g^{-1}), titratable acidity (malic acid %), and pH were done with the previously described methods. To determine the concentration of reducing sugars (mg g^{-1}), the method used by Nelson (1944) and by Somogy (1952) was used. First, the sugar extraction was done with 80% ethanol (v/v) and the sample was stored at 4 °C. After 15 days, the sample was dissolved with 20 mL distilled water and 1 mL of this solution was placed in a flat bottomed test tube with 1 mL Nelson-Somogy reactive. This reactive was prepared by mixing 2.5% anhydrous sodium carbonate, 2.5% potassium sodium tartrate, 2% sodium bicarbonate, 2% anhydrous sodium sulfate, and 15% copper sulfate. Subsequently, the test tube was placed in boiling water for 20 min, cooled with water, and added 1 mL arsenic molybdate reactive (5.5% ammonium molybdate, 12% sodium arsenite, and 98.8% sulfuric acid). Immediately after this, 7 mL distilled water was added and absorbance was registered at 540 nm, using a mixture of 8 mL distilled water, 1 mL Nelson-Somogy reactive, and 1 mL arsenic molybdate reactive as blank. The content of reducing sugars was calculated using a standard glucose curve.

Statistical analysis

To evaluate the changes in total sugars, reducing sugars, pH, titratable acidity, and color through time, a multivariate analysis of variance (ANOVA) and mean comparisons by Tukey's test ($P < 0.05$), with the statistical SAS software (NC, USA), for personal computer were carried out.

Results and discussion

Fruit growth

The changes in fresh mass, polar diameter, and equatorial diameter through time in the *Crataegus mexicana* Mocino & Sessé cvs. Quetzalli and Atlatex, indicate that the tejocote fruit growth follows a double sigmoid growth pattern (Figure 1), which is different from the single sigmoid pattern reported by Li *et al.* (2015) for the species *Crataegus pinnatifida* ('Dajinxing'). It must be added that the *Crataegus* genus belongs to the *Rosaceae* family (Phipps *et al.*, 2007), where the fruits of diverse species show double sigmoid growth with three phases (Coombe, 1976).

In the present study, to depict the double sigmoid growth

TABLE 1. Parameters of the double sigmoid model obtained for tejocote (*Crataegus mexicana* Moc. & Sessé) fruits.

Cultivar	First sigmoid			Second sigmoid			R^2	RMSE
	$m_1 \pm sd$	$m_2 \pm sd$	$m_3 \pm sd$	$m_4 \pm sd$	$m_5 \pm sd$	$m_6 \pm sd$		
'Quetzalli'								
FFW (g)	3.34 ± 0.24	0.09 ± 0.02	38.30 ± 2.66	16.50 ± 0.77	0.04 ± 0.003	167.00 ± 1.85	0.99	0.58
EFD (mm)	14.11 ± 2.41	0.15 ± 0.04	27.95 ± 1.16	20.80 ± 6.37	0.02 ± 0.008	154.80 ± 11.99	0.97	1.23
PFD (mm)	18.32 ± 0.70	0.07 ± 0.01	27.29 ± 1.57	7.74 ± 1.00	0.05 ± 0.013	140.64 ± 4.63	0.96	1.18
'Atlatex'								
FFW (g)	1.98 ± 0.32	0.18 ± 0.09	26.12 ± 2.69	23.42 ± 3.25	0.03 ± 0.003	190.15 ± 9.35	0.99	0.62
EFD (mm)	16.17 ± 1.28	0.07 ± 0.01	16.99 ± 1.46	13.97 ± 2.50	0.03 ± 0.008	145.96 ± 5.52	0.97	1.05
PFD (mm)	17.77 ± 1.15	0.05 ± 0.01	12.46 ± 2.38	8.59 ± 1.77	0.04 ± 0.012	148.35 ± 6.08	0.96	0.94

FFM: fresh fruit mass (g).
EFD: equatorial fruit diameter (mm).
PFD: polar fruit diameter (mm).
m_1 and m_4: accumulated growth (g or mm).
m_2 and m_5: maximum growth rate (g day^{-1} or mm day^{-1}).
m_3 and m_6: days of maximum growth rate.
sd: standard deviation ($n = 8$).

pattern of both cultivars, the adjustment of equation (1) to the observed data was useful to characterize the three phases. This procedure resulted in goodness of fit terms 95% representative (Table 1); and, the maximum growth rate, accumulated growth, and days of maximum growth rate parameters were determined, after the non-linear regression, being their respective values similar and of the same order of magnitude as the experimental data (Table 1). Therefore, phase I represented the first sigmoid curve, with a significant increase in fresh mass, polar diameter, and equatorial diameter, lasting from fruit set for 60 days in 'Quetzalli' and 45 days in 'Atlatex' (Figure 1). This suggests that phase I (first sigmoid) duration was longer in 'Quetzalli' than 'Atlatex'. On the other hand, during the beginning of phase I, equatorial and polar diameters between both cultivars showed differences in size being respectively around 5 mm in 'Quetzalli' (Figure 1 C and E) and around 10 mm in 'Atlatex' (Figure 1 D and F). Other notorious differences observed in phase I were on the maximum growth rate parameters determined for each change studied. In case of fresh mass, the maximum growth rate determined was higher in 'Atlatex' (0.18 ± 0.09 g day^{-1}) than 'Quetzalli' (0.09 ± 0.02 g day^{-1}) (Table 1). In the case of equatorial diameters, the maximum growth rate was lower in 'Atlatex' (0.07 ± 0.01 g day^{-1}) than in 'Quetzalli' (0.15 ± 0.04 g day^{-1}). In the case of polar diameters, the maximum growth rate was similar in both cultivars (Table 1). Therefore, phase I suggests a rapid growth of the mesocarp and endocarp, followed by a phase II of embryo development and hardening of the endocarp. According to Figure 1 and Table 1, phase II represented a period with non-significant changes in the three growth variables studied that lasted 30 days in 'Quetzalli' and 45 days in 'Atlatex'. Phase II completed at 90 days after fruit set in both cultivars. The differences in phase II period suggested that embryo development and hardening of the endocarp took place in longer time in 'Atlatex' than 'Quetzalli'. Phase III represents a rapid growth of the mesocarp and accumulation of reserve substances (Coombe, 1976). Consequently, for the present study, phase III followed phase II by observing a second sigmoid curve

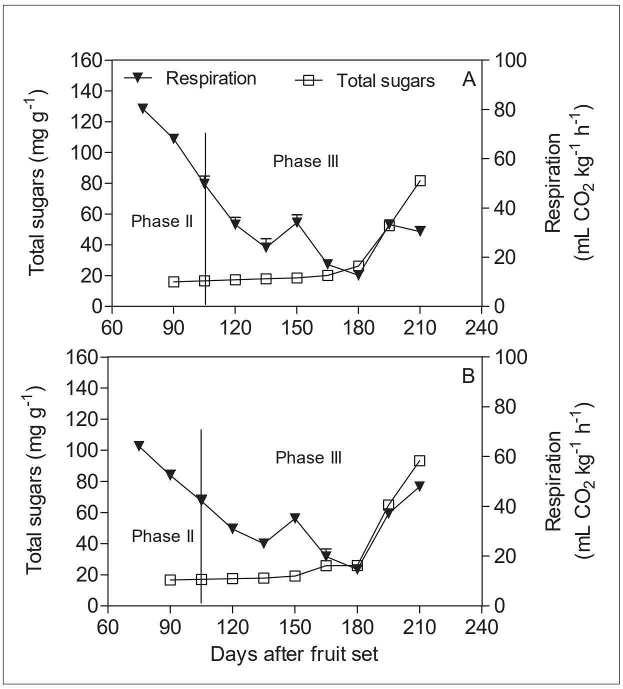

FIGURE 2. Respiration rate and total sugars of tejocote fruits of two cultivars (A) 'Quetzalli' and (B) 'Atlatex' from fruit set to harvest mature. Data are mean values ± standard deviations ($n = 3$).

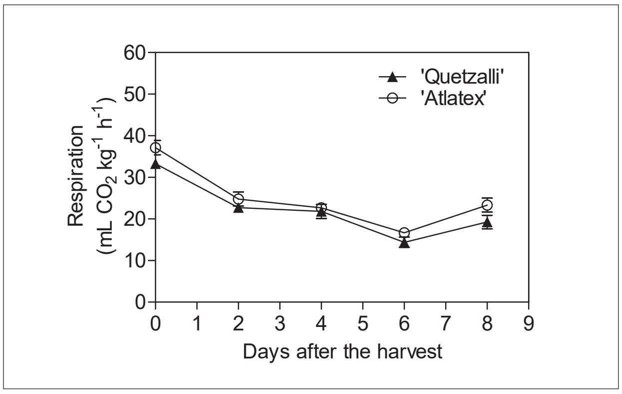

FIGURE 3. Respiration rate of tejocote fruits (cvs. Quetzalli and Atlatex) stored at 22 ± 2 °C and 50–60% relative humidity for 8 days. Data are mean values ± standard deviations ($n = 3$).

TABLE 2. Changes in the malic acid content and pH of tejocote fruits (cvs. Quetzalli and Atlatex) during their growth. DAS: days after fruit set, CV: variation coefficient, HSD: honest significant difference.

DAS	Titratable acidity (% malic acid)		pH	
	'Quetzalli'	'Atlatex'	'Quetzalli'	'Atlatex'
90	1.01[a]	0.85[a]	3.6[b]	3.6[c]
105	0.99[a]	0.83[ab]	3.6[b]	3.6[c]
120	0.88[ab]	0.76[abc]	3.6[b]	3.7[cb]
135	0.89[ab]	0.74[bcd]	3.6[b]	3.8[ab]
150	0.82[bc]	0.74[bcd]	3.6[b]	3.8[ab]
165	0.81[bc]	0.73[bcd]	3.6[c]	3.8[ab]
180	0.81[bc]	0.71[bcd]	3.6[c]	3.8[ab]
195	0.74[cd]	0.66[cd]	4.1[a]	4.0[a]
210	0.66[d]	0.64[d]	3.8[ab]	3.8[b]
CV (%)	*5.33*	*5.63*	*1.73*	*2.03*
HSD	*0.13*	*0.12*	*0.16*	*0.22*

Same letters in each column indicate statistical similarity according to the Tukey's test ($P<0.05$), $n=3$.

that lasted 120 days in both cultivars (Figure 1). Despite that the maximum growth rate parameters determined in phase III (second sigmoid) decreased compared to phase I (first sigmoid) (Table 1), the fruits continued their growth. According to the fresh mass, polar diameter, and equatorial diameter at the end of phase III, the fruit growth stopped 210 DAS in both cultivars, reaching a mean fresh mass of 17.6 g for 'Quetzalli' and 16.2 g for 'Atlatex'. In this last phase, the fresh mass of the fruits increased by 4.78 and 4.83 times in 'Quetzalli' and 'Atlatex', respectively, resulting in an increase of the edible part. The equatorial and polar diameter ratio showed a slightly elongated shape in 'Quetzalli' and a rounded shape in 'Atlatex'. This is important in regard to fruit yield and quality at the time of harvest. These results could present variability in function of the year factor.

Respiration, total sugars, and titratable acidity

Kader (1987) described the respiratory metabolism to be very high during the first growth stages of the fruits and tends to decrease as the fruits reach their final size. The tejocote fruit of both cultivars showed high respiratory activity during phase II, with changes from 80.4 and 64.1 mL CO_2 kg^{-1} h^{-1} for 'Quetzalli' and 'Atlatex', respectively, at the beginning of said phase, to 49.8 and 52.4 mL CO_2 kg^{-1} h^{-1}, in the same order, at the end of the phase (Figure 2 A and B). Tissue formation has been reported to require a high supply of energy for the interconversion of photosynthetic sucrose into structural compounds (Monselise, 1986). This metabolism is important for the development of the embryo and other structures of the seed. There was a sudden increase in the respiration rate in phase III in both cultivars, with a maximum at 150 DAS, which suggests a high metabolic activity mainly related with the formation of complex phenolic compounds (Banderas-Tarabay *et al.*, 2015). To this regard, immature tejocote fruits have a highly stringent taste that decreases as the fruits maturation. Starting on 180 DAS, the respiration rate increased until it reached 210 DAS with 30.4 and 47.9 mL CO_2 kg^{-1} h^{-1} for 'Quetzalli' and 'Atlatex', respectively (Figure 2 A and B), due to the energy requirements for the changes associated with fruit maturation. To this regard, there was a significant increase in the total sugars content during this period from 26 mg g^{-1} for both cultivars at 180 DAS, to 82 and 93 mg g^{-1} for 'Quetzalli' and 'Atlatex', respectively, at 210 DAS. Moreover, the malic acid content decreased from 0.81 to 0.66% in 'Quetzalli' and from 0.71 to 0.64% in 'Atlatex' (Table 2). In studies on 49 tejocote genotypes (Franco-Mora *et al.*, 2010), total sugars contents from 64 to 129 mg g^{-1} were reported, as well as 1 to 6% malic acid, which places the cultivars in this study as fruits with acceptable taste given their low acidity and high sugar/acid ratio (124.2 'Quetzalli' and 145.3 'Atlatex').

Postharvest behavior

During postharvest, both cultivars showed a non-climacteric respiratory behavior decreasing the respiration rate from 33.3 ('Quetzalli') and 37.1 ('Atlatex') mL CO_2 kg^{-1} h^{-1} at harvest to 19.3 and 23.3 mL CO_2 kg^{-1} h^{-1}, for the same cultivars, after eight days storage at 20±2 °C (Figure 3). According to Kader (2002), this behavior is related with changes associated with senescence, with the subsequent loss of quality and limitation of shelf life. During this period,

TABLE 3. Changes in the total sugar, reducing sugar and malic acid contents of tejocote fruits (cvs. Quetzalli and Atlatex) stored at 20±2 °C and 50–60% relative humidity for 8 days. CV: variation coefficient, HSD: honest significant difference.

	'Quetzalli'	'Atlatex'
Total sugars (mg g^{-1})		
0 day	81.7[a]	93.0[a]
8 days	87.0[a]	97.0[a]
CV (%)	*5.65*	*4.60*
HSD	*1.08*	*0.99*
Reducing sugars (mg g^{-1})		
0 day	23.7[a]	27.0[a]
8 days	27.0[a]	30.3[a]
CV (%)	*11.62*	*2.85*
HSD	*0.67*	*0.19*
Titratable acidity (% malic acid)		
0 day	0.69[a]	0.64[a]
8 days	0.66[a]	0.53[a]
CV (%)	*9.23*	*10.65*
HSD	*0.14*	*0.14*

Same letters in each column indicate statistical similarity according to the Tukey's test ($P<0.05$), $n=3$.

TABLE 4. Changes in color parameters of tejocote fruits (cvs. Quetzalli and Atlatex) stored at 22 ± 2 °C and 50–60% relative humidity for 8 days. L*: luminosity, °h: hue angle, C: chroma, CV: variation coefficient; HSD: honest significant difference.

Storage time (days)	L*		°h		C	
	'Quetzalli'	'Atlatex'	'Quetzalli'	'Atlatex'	'Quetzalli'	'Atlatex'
0	60.1 a	59.1 a	108.9 a	107.0 a	31.0 a	30.0 a
2	60.0 ab	58.9 a	108.2 ab	106.1 a	31.1 a	30.1 a
4	58.1 bc	57.1 ab	104.9 ab	102.8 ab	30.4 a	29.7 a
6	58.1 bc	57.1 ab	104.4 b	102.6 ab	30.3 a	29.5 a
8	57.4 c	56.3 b	104.0 b	100.6 b	29.6 a	29.2 a
CV (%)	3.4	4.3	2.5	4.7	4.4	4.9
HSD	2	2.5	2.6	4.9	1.3	1.4

Same letters in each column indicate statistical similarity according to the Tukey's test ($P < 0.05$), $n = 9$.

weight losses increased to 13% in both cultivars, and the fruits showed wilting symptoms from water loss through lenticels and floral conducts, as is the case in other *Pomaceaes* (Hulme and Rhodes, 1971).

There were no significant changes in total sugar contents, reducing sugar contents, or malic acid concentrations (Table 3). The external color showed a significant decrease ($P < 0.05$) in the color luminosity (L) from 60.1 to 57.4 for 'Quetzalli' and from 59.1 to 56.3 for 'Atlatex' (Table 4), due to changes in the amount and composition of epicuticular wax, as reported in apple (Kolattukudy, 1984). The hue angle (h°) decreased as well from 108.9 to 104.0 in 'Quetzalli' and from 107 to 100.6 in 'Atlatex'; this change is mainly associated to a loss in green coloring. There was no significant change in chroma. This indicates that weight and color losses are the main parameters that characterize the loss of quality and the shelf life of tejocote fruits.

Conclusion

The growth of tejocote fruit (*Crataegus mexicana* cvs. Quetzalli and Atlatex), as evaluated for changes in fresh mass, polar and equatorial diameters, adjusts to a double sigmoid growth pattern completed in a period of 210 DAS, and includes differences during phases I and II between the cultivars. In 'Quetzalli', the growth of the mesocarp and endocarp (phase I) require longer than 'Atlatex'; however, in 'Atlatex' the development of the embryo and hardening of the endocarp (phase II) require a longer period than in 'Quetzalli'. This study establishes that the fruit maturation period starts on the last fourth of the growth period and is characterized by an increase in the respiration rate and total sugar content, making necessary some knowledge on the biosynthetic profiles of other chemical compounds derived from the plant secondary metabolism, among others. Further studies should focus on the regulatory role of photosynthates, phytohormones, water, and nutrients during all three growth phases.

During postharvest, the tejocote fruit showed a non-climacteric behavior as characterized by no changes in the respiration rate, sugar and malic acid contents. Moreover, the fruit storage for eight days at 22 ± 2 °C resulted in high weight loss, decrease in luminosity, yellowing, and an appearance of becoming old, which all parameters characterize fruit quality. Further research is needed on technologies controlling these parameters for the preservation of tejocote fresh fruit.

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Received: Sep. 29, 2016
Accepted: Nov. 22, 2016