



Postharvest of four ecotypes of mexican plum (*Spondias purpurea* L.) grown in Morelos, Mexico

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Abstract

Mexico has a great diversity of Mexican plum, a fruit tree with a lot of potential to be commercially cultivated, but few post-harvest studies have been carried out on known ecotypes. The objective of this study was to characterize the postharvest behavior of four Mexican plum ecotypes grown in Morelos, Mexico, this information is basic to develop postharvest technologies oriented to increase shelf-life. Fruits of 'Amarilla', 'Castilla', 'Chapilla' and 'Roja' Mexican plum (*Spondias purpurea* L.) with epidermal color development of 50 or 75 % were collected to determine some changes during ripening. Results suggested that 'Amarilla' and 'Chapilla' showed a maximum respiration peak 3 d after harvest with significant differences between ripening stages. Respiration decreased constantly with no differences between ripening stages for 'Castilla' and 'Roja'. Hue (h^*) decreased from yellow color tendency ($63 \leq h^* \leq 86$) to orange and red color ($31 \leq h^* \leq 67$), with differences between ripening stages. Lightness (L^*) reduced from 46-48 % to 31-32 % and chroma (C^*) increased from 18-25 to 36-42, suggesting that the color purity increased during ripening. Total soluble solids and titratable acidity increased from 9.4 to 15.5 °Brix and from 0.27 to 0.48 %, respectively, with significant differences between ripening stages at the beginning of the experiment, which were not maintained during ripening. Vitamin C increased during ripening in the four ecotypes and no differences were detected between ripening stages. In conclusion, differences in behavior were detected among ecotypes evaluated with few differences attributed to harvest maturity, which should be considered in the development of postharvest technologies for this species.

► **Keywords:** Titratable acidity, color, respiration, total soluble solids, vitamin C.

Introduction

The Mexican plum (*Spondias purpurea* L.) is a fruit tree native to Mesoamerica, where it is also known as 'jocote' (from the Nahuatl Xocotl or sour fruit) (Duarte & Paull, 2015). More specifically, the center of origin is considered to be the western region of Mexico (Jalisco, Nayarit and Michoacán) and the centers of genetic diversity are the Balsas Depression and the Yucatán Peninsula (Fortuny-Fernández, Monserrat Ferrer, & Ruenes-Morales, 2017). The genus *Spondias* con-

tains 17 species, of which seven are found in the Neotropics and 10 in the Asian tropics. At least six species are grown, of which three are Asian and three are American: *Spondias mombin*, *S. purpurea* and *S. tuberosa* (Miller, 2011). Mexico reports the presence of *S. mombin*, *S. radlkoferi*, *S. purpurea* and *S. lutea* in 20 states, mainly in the southern part and near the coast (Cruz & Gutiérrez, 2012). Although Mexican plum is multiplied for commercial purposes, information about current genotypes is scarce, mainly because its cultivation is based on informal agriculture in backyard orchards,

live fences and small farms, and wild types are found in areas with difficult access (Alia-Tejagal et al., 2012). However, there are some statistical data reported in different publications, which indicate that Mexico produces plums in 21 states, concentrated in Puebla (3 554 ha), Chiapas (2 327 ha) and Sinaloa (1 510 ha), which together reach an area of 7 391.5 ha, which represents 61 % of the total area harvested in the country (Cruz & Rodríguez, 2012).

S. purpurea trees are used as live fences; its leaves are highly palatable to livestock and its fruit is consumed in its ripening stage (Ramírez-Hernández et al., 2008). In some regions, such as Chiapas, it is cultivated commercially with incipient agronomic management involving fertilization and pest control (Alia-Tejagal et al., 2012). Fruits of the Mexican plum are oblong, round or ovoid drupes; with different sizes and masses ranging between 2 and 5 cm and between 4 and 33 g, respectively, with smooth to semi-smooth thin epicarp, with red, yellow, reddish brown, orange or purple coloration when ripe, with thick and fibrous endocarp and mesocarp of pleasant flavor and aroma (Maldonado-Astudillo et al., 2014). The ripe fruit of the Mexican plum provides high caloric density, vitamin C and moderate proportion of minerals such as potassium and calcium (Kozioł & Macía, 1998), in addition to antioxidant compounds such as phenols and carotenoids (Moo-Huchin et al., 2014).

The Mexican plum can be divided into dry season and wet season groups, which mainly refers to the fruiting and harvesting stage (Avitia, Castillo, & Pimienta, 2003; Miller, 2011). Mexican 'Cuernavaca' plum fruit, from wet season, once harvested, shows increased ethylene and CO₂ production in soluble solids content, total sugars, hue, total carotenoids, and weight loss, as well as a significant decrease in fruit firmness and titratable acidity (Maldonado-Astudillo et al., 2014). In general, it is mentioned that Mexican plum fruit has a short postharvest life, between 5 and 6 d, at room temperature (Duarte & Paull, 2015). Suárez et al. (2017) indicate that content of phenols, flavonoids, total carotenoids and antioxidant activity was higher when the fruit reached maximum ripening and high positive correlations were detected between bioactive compounds and antioxidant activity, in the wet season ecotype 'Cuernavaca'. About 20 Mexican plum varieties have been described in Mexico (Avitia, et al., 2003), but the physical, chemical and physiological changes in postharvest at different stages of fruit ripening have not been evaluated.

In the state of Morelos, Mexico, some physical, chemical and physiological characteristics of some ecotypes of the region at consumption maturity have been evaluated (Alia-Tejagal et al., 2012; Álvarez-Vargas et al., 2017; Maldonado, Alia, Nuñez-Colín, Hernández, & Martínez, 2017); however, changes at ripening stages other than consumption maturity have not been evaluated. Therefore, this experiment evaluates some postharvest changes of four

dry climate Mexican plum ecotypes, collected in Morelos, Mexico, because this information can be used for further development of postharvest technologies to maintain longer shelf life.

Materials and Methods

Site location and plant material

Between 50 and 60 fruits were collected from trees of four Mexican plum ecotypes in municipalities in the south of Morelos (Table 1). Fruits were harvested at two ripening stages with 50 % epidermis color and 75% epidermis color, between 8:00 and 10:00 AM. The material was transferred to the Agricultural Production Laboratory of the Faculty of Agricultural Sciences at the Universidad Autónoma del Estado de Morelos, where it was brought to the laboratory temperature and subsequently immersed in a 1% chlorine solution for 1 min and left to dry on paper (Sanitas®) for 3 h. Fruits with no mechanical or pathogen damage were selected for the experiment.

Experimental organization

Fruits in each ecotype were divided as follows: (1) fruits with 50 % of characteristic epidermis color and (2) fruits with 75 % of characteristic epidermis color. Destructive and non-destructive sampling was carried out at 0, 3, 6, 9 and 12 d after harvest. The fruits were kept in trays during the evaluation period. The experimental unit was one fruit with six repetitions. The experimental design was completely randomized.

Variables analyzed

Color

The following color parameters were determined: lightness (L*), a* y b*, in the epicarp of the equatorial zone using a manual spectrophotometer (X-Rite 3290®, USA). The values of a* and b* were used to determine hue with the calculation ($h^* = \arctan^{-1} b^*/a^*$) and chroma with the following calculation ($C^* = (+)$) (Neguerula, 2012).

Respiration

Respiration rate was quantified by a static system, which consisted of placing two intact fruits in hermetically sealed containers for 1 h. Subsequently, a 1 mL sample was taken from the headspace for injection into a gas chromatograph (Agilent Technologies 7890A GC, USA), with an open type of column with porous silica layer packing, simultaneously connected to a thermal conductivity detector at 170 °C. The injector and chromatograph oven were maintained at 150 and 80 °C, respectively, during evaluations. Quantification was performed using a standard provided by PRAXAIR®, Mexico.

Table 1. Evaluated ecotypes of Mexican plum from Morelos.

Ecotype	Site of collection	Coordinates [†]	Elevation (m) [†]
'Castilla'	Cuautlita	18°42'02.02" N, 99°22'33.41" O	954
'Chapilla'	Cuautlita		
'Amarilla'	Cuautlita		
'Roja'	Cuahuchichinola	10°40'02.02" N, 99°22'34.20" O	941

[†]: Google Earth Pro (2018).

Titrateable acidity (TA)

Titrateable acidity was determined using the procedure described by Suárez et al. (2017), where 1 g of fruit tissue (epidermis + pulp) was finely chopped and homogenized with 12 mL distilled water in an Ultraturrax equipment (IKA®, USA). Subsequently, the mixture was filtered, and 5 mL of liquid was taken for titration with 0.1 N NaOH, using phenolphthalein as indicator. The results were expressed as percentage of citric acid.

Total soluble solids (TSS)

TSS content was determined from two drops of the filtrate obtained to determine titrateable acidity, placed in a digital refractometer (ATAGO PAL-1®, Japan). The results were reported in °Brix.

Vitamin C

The methodology proposed by Jagota and Dani (1982) was followed, which is a colorimetric technique for the estimation of vitamin C, using the Folin-Ciocalteu (FC) reagent. We weighted 1 g of sample was weighed and homogenized it with 4 mL of 10 % w/v trichloroacetic acid (TCA). The mixture was placed in an ice bath for 5 min, centrifuged at 11 290 x g for 20 min at 4 °C. Aliquots of 0.5 mL of the supernatant were taken and mixed with 1.5 mL of double distilled water and 200 µL of FC reagent. The mixture was left to react in the dark for 15 min and absorbance was read at 760 nm. A standard curve was constructed with ascorbic acid to estimate the vitamin C content. Total concentration was expressed as mg · g⁻¹ fresh weight.

Data analysis

Data were analyzed by comparison of means with a T-test, using the SigmaPlot 14.0 program (Systat Software, Inc., San Jose California USA). The results were represented graphically with the mean of observations and their standard error.

Results and Discussion

Respiration

Respiration of 'Amarilla' and 'Chapilla' ecotypes showed a typical climacteric pattern. The maximum CO₂ production

was determined three days after harvest, with significant differences between ripening stages, specifically in preclimacteric, for the 'Amarilla' ecotype, or in preclimacteric and postclimacteric, for 'Chapilla' (Figure 1A and 1C). For 'Castilla' and 'Roja' ecotypes, the climacteric pattern was not evident, because a constant decrease in respiration was detected, which could be considered the postclimacteric phase, since maximum production values were observed on the initial day of evaluation and no differences in respiration were detected between ripening stages within each ecotype (Figure 1 B and D). The 'Castilla' ecotype showed on average the highest respiration activity (Figure 1B).

Almeida, Singh, and Holschuh (2008) reported that, in postharvest, red mombin plum (*Spondias purpurea* L.) shows a state of preclimacteric minimum, followed by a sudden increase in respiration, reaching a maximum (climacteric peak) and subsequent decrease in respiratory activity (postclimacteric) at senescence. The climacteric maximum was reported after 5.6 d at 28 °C. In the present study, 'Amarilla' and 'Chapilla' reached maximum respiration after 3 d, i.e. 2.6 d earlier than reported by de Almeida et al. (2008). This was because these authors harvested fruits at a stage with 100 % green coloration, while in the present study the harvest was at 50 or 75 % typical color of the fruit epidermis.

Different authors have reported that *Spondias purpurea* L. fruits, shows climacteric behavior; however, some others did not detect climacteric behavior in evaluations carried out on the same species (Mohammed et al., 2019). In the present experiment, climacteric was not observed in the ecotypes 'Castilla' and 'Roja' (Figure 1 C and D). Maldonado-Astudillo et al. (2014) indicated that due to variation in CO₂ production behavior, it is difficult to determine whether Mexican plum is climacteric or not. In the present study, the non-detection of CO₂ production maxima in 'Castilla' and 'Roja' can be attributed to: (1) that fruits were harvested at a stage where climacteric had already occurred; (2) that sampling every three days did not favor the detection of maximum production and (3), that these ecotypes show a different respiration pattern than climacteric.

The few differences in respiration rate between ripening stages in each ecotype has been reported previously by Suárez et al. (2017), who detected no differences in CO₂

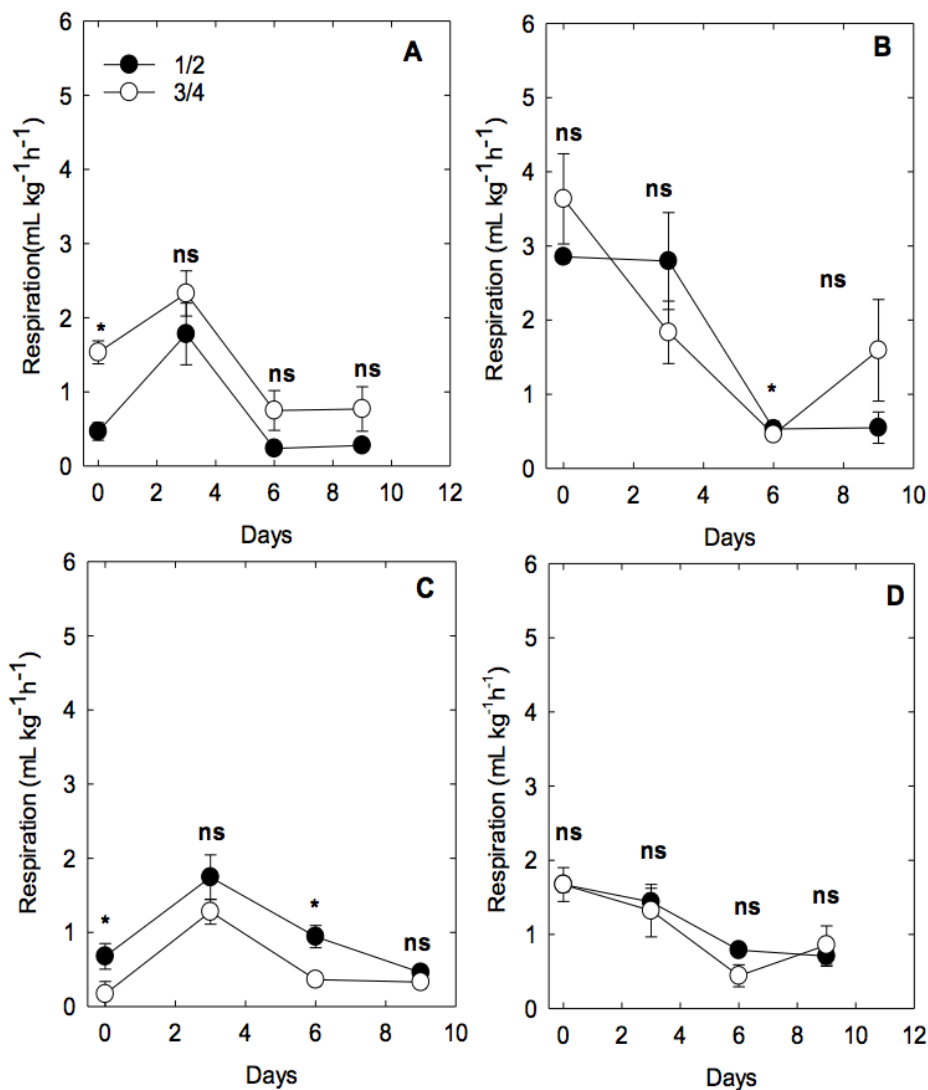


Figure 1. Respiration in (A) 'Amarilla', (B) 'Castilla', (C) 'Chapilla' and (D) 'Roja' Mexican plum fruit after being harvested at two ripening stages: 50 % (1/2) and 75 % (3/4) color. Each point represents the mean of six observations and its standard error. *: significant at 0.05 according to the T-test.

production in the wet season ecotype 'Cuernavacaña' harvested at green stage, 50, 75 and 100 % of fruit epidermis color. The higher respiration rate in 'Castilla' suggests a shorter postharvest shelf life than the rest of the ecotypes. Kader and Yahia (2011) indicated that decay rate is inversely related to aerobic respiration rate in tropical and subtropical fruits.

Color parameters

The color of ecotype 'Amarilla' changed from greenish-yellow ($h^* = 83$) tending to orange ($h^* = 68$) in fruit harvested at 50 % color modification progress, while fruit harvested at 75 % color reached values tending more to orange ($h^* = 54$) (Figure 2I). Lightness and chroma increased on the third day of evaluation and subsequently

decreased to values similar to those at the beginning of the experiment, showing differences between ripening stages only on the third day of evaluation (Figure 2A and 2E).

For the ecotype 'Castilla', the color of fruits harvested at 50 % showed a significantly greater tendency to orange ($h^* = 67.3$) and subsequently changed to purple red; while fruits at 75 % showed a red color tending to purple ($h^* = 27$) during 8 d (Figure 2J). The t-test determined differences in color due to harvest stage at the beginning and third day of evaluation (Figure 2J). Chroma and lightness were different at the beginning of evaluations at both ripening stages; subsequently, lightness gradually decreased and chroma increased, maintaining a constant value thereafter, with no differences due to ripening stage detected (Figure 2B and 2F).

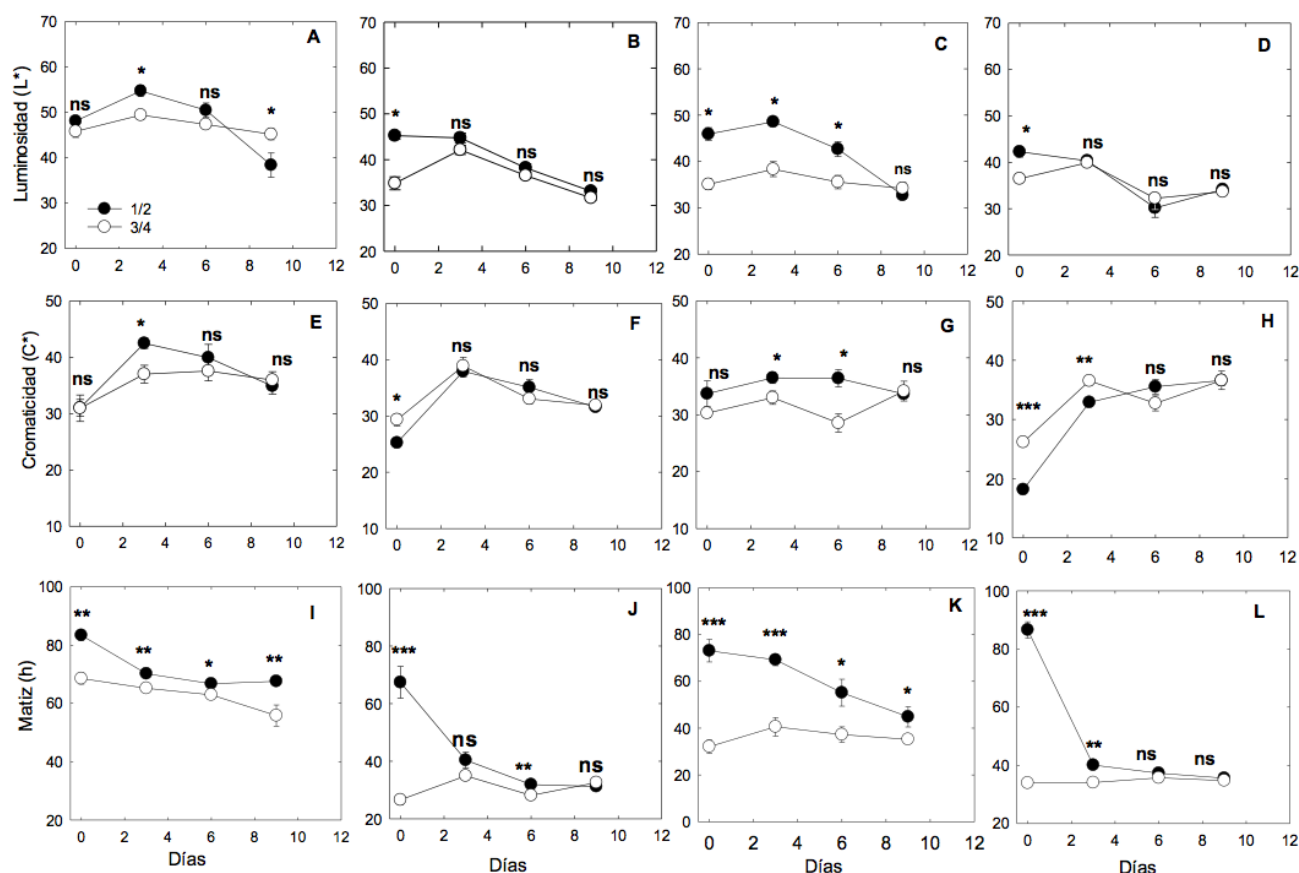


Figure 2. Mexican plum fruit color parameters (A, E, I) 'Yellow', (B, F, J) 'Castilla', (C, G, K) 'Chapilla' and (D, H, L) 'Red' after their cropping in two stages of maturity: 50 % (1/2) and 75 % (3/4) of color. Each point represents the standard error. *, **, ***: significant for 0.05, 0.01 and <0.0001, respectively, according to the t-test. ns: non-significant.

For the ecotype 'Chapilla', at the beginning of evaluations, fruits with 75 % color showed a tendency to red ($h^* = 31$), while fruits with 50 % color tended to yellow ($h^* = 74$), maintaining significant differences between ripening stages throughout the evaluation period (Figure 2K). Chroma and lightness parameters showed differences between ripening stages until the sixth day of evaluation; thus, fruits with 75 % color had lower lightness and were opaquer than fruits with 50 % pigmentation (Figure 2C and 2G). Both parameters decreased with the ripening process and reached similar values after 9 d of evaluation (Figure 2C and G).

The ecotype 'Roja', harvested with 50 % pigmentation, showed a tendency to yellow ($h^* = 86.5$) and fruits with 75 % color tended to red ($h^* = 34$), indicating differences between ripening stages at the beginning of evaluations. However, after the sixth day of evaluation, no differences between ripening stages were detected (Figure 2L). Lightness decreased during the evaluation process, indicating that the color became opaque as it matured, with no differences between ripening stages (Figure 2D). On the other hand, chroma increased showing differences between ripening stages during the first 3 d of evaluation and subsequently similar values of chroma were detected (Figure 2H).

Maldonado-Astudillo et al. (2014) indicated that the wet season ecotype 'Cuernavaca' harvested green, half-green or three-quarters ripe, had an increase and subsequent decrease in lightness. On the other hand, chroma only increased in unripe harvested fruit, while few changes occurred in ripe or fully colored fruit. Finally, hue decreased from green ($h^* = 93.6$), medium green ($h^* = 73.9$) or ripe ($h^* = 53.2$) to red ($h^* =$ between 53 and 48.5). These changes were similar to that found in this study. The hue parameter was the most changeable and the one that helped to better differentiate the ripening stages, compared to brightness and hue parameters (Figure 2). Mexican plums show different colors ranging from green, yellow, orange, red, purple, but no focused study on pigments that define these colors and concentrations of each pigment in the Mexican varieties of *S. purpurea* is available.

Total soluble solids (TSS)

At the beginning of the experiment, TSS in fruits of the ecotype 'Amarilla' with 75 % color advance had a value of 9.4 °Brix and fruits with 50 % ripening had a value of 11.6 °Brix. Subsequently, TSS remained between 10.4 and 11.1 °Brix (Figure 3A). In the ecotype 'Castilla', fruits with

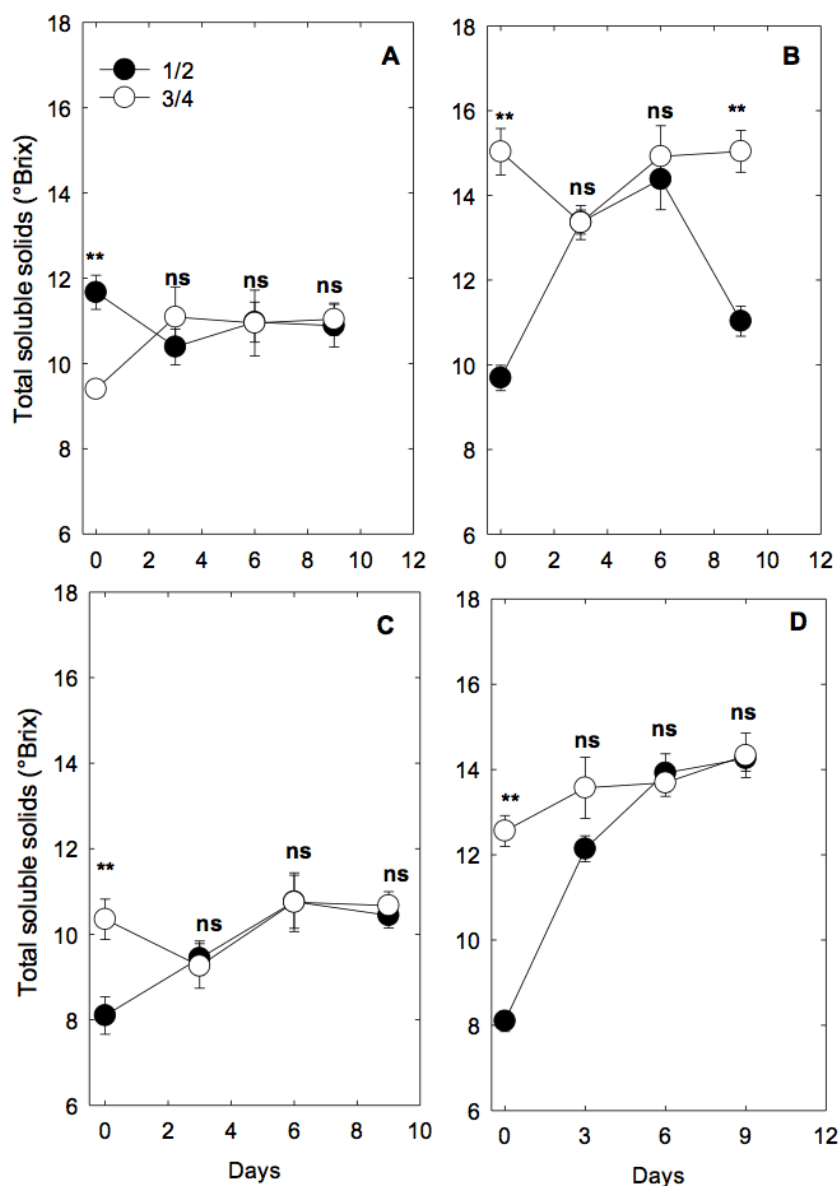


Figure 3. Total soluble solids in (A) 'Amarilla', (B) 'Castilla', (C) 'Chapilla' and (D) 'Roja' Mexican plum fruit after harvest at two ripening stages: 50 % (1/2) and 75 % (3/4) color. Each point represents the mean of six observations and its standard error. *: significant at 0.05 according to the T-test. ns: non-significant.

50 % color had an initial value of 9.7 °Brix, reaching a maximum of 14.3 °Brix after 9 d of evaluation, while fruits harvested at 75 % ripening started with 15 °Brix and remained between 13.3 and 15 °Brix during the evaluation period (Figure 3B). In the case of the ecotype 'Chapilla', fruits with 50 % color had 8.1 °Brix at the beginning of evaluations, while fruits with 75 % color had 10.3 °Brix; subsequently, fruits of both ripening stages showed between 9.4 and 10.6 °Brix, without significant differences (Figure 3 C). In the ecotype Roja', fruits with 50 % ripening showed 8.1 °Brix and fruits with 75 % color had 12.5 °Brix, with no significant differences between 3 and 9 d of evaluation, remaining between 12.1 and 13.5 °Brix (Figure 3D).

The content of TSS in Mexican plum varies between 3.2 and 27.0 °Brix (Maldonado-Astudillo et al., 2014). During ripening, TSS increases from 9.1 °Brix at the pre-climacteric stage to 13.7 °Brix at the maximum climacteric stage (Almedia et al., 2008). This behavior was observed in 'Castilla', 'Chapilla' and 'Roja', but not in 'Amarilla'. The amount of TSS is influenced by variety, ripening stage at the time of harvest, storage conditions or postharvest treatments evaluated (Maldonado-Astudillo et al., 2014). TSS concentration was significantly different at the beginning of evaluations, however, subsequently all ecotypes had very similar values, which has been previously reported for the wet season ecotype 'Cuernavacaña' (Maldonado-Astudillo

et al., 2014). ‘Castilla’ and ‘Roja’ were the ecotypes with higher TSS concentration, reaching between 13.5 and 15.0 °Brix, while ‘Amarilla’ and ‘Chapilla’ accumulated between 9.4 and 13.5 °Brix (Figure 3).

Titrateable acidity

Titrateable acidity had few differences between ripening stages at the beginning of evaluations in the ecotype ‘Chapilla’ (Figure 4 A), while there were differences on the third day of evaluation in the ecotype ‘Castilla’ (Figure 4B). Titrateable acidity in *Spondias purpurea* ranges from 0.2 to 3.05 %, although some ecotypes may show 0.012 %. (Maldonado-Astudillo et al., 2014; Maldonado et al., 2017). Acidity decreased in the four ecotypes during ripening from between 0.28 and 0.45 % to between 0.19 and 0.20 % (Figure 4). Suárez et al. (2017) indicated that acidity in Mex-

ican plum ‘Cuernavaqueña’ decreased from 0.42 -0.48 % to 0.23 -0.27 % in pulp and epicarp. ‘Roja’ and ‘Amarilla’ had the highest titrateable acidity values, between 0.28 and 0.48 %, while ‘Castilla’ and ‘Chapilla’ maintained values between 0.27 and 0.37 % (Figure 4). Valero and Serrano (2010) indicated that, for tomatoes, acidity ranges between 0.4 and 1.7 %, for sweet cherries between 1 and 1.5 % and for Spanish plum between 0.7 and 1.6 %, which indicated that the Mexican plum ecotypes evaluated are considered to have low acidity.

Vitamin C

Vitamin C content increased in all ecotypes, no matter the ripening stage (Figure 5), except for fruit harvested at 75 % color of the ‘Amarilla’ ecotype, where the lowest vitamin C content was found between the third and

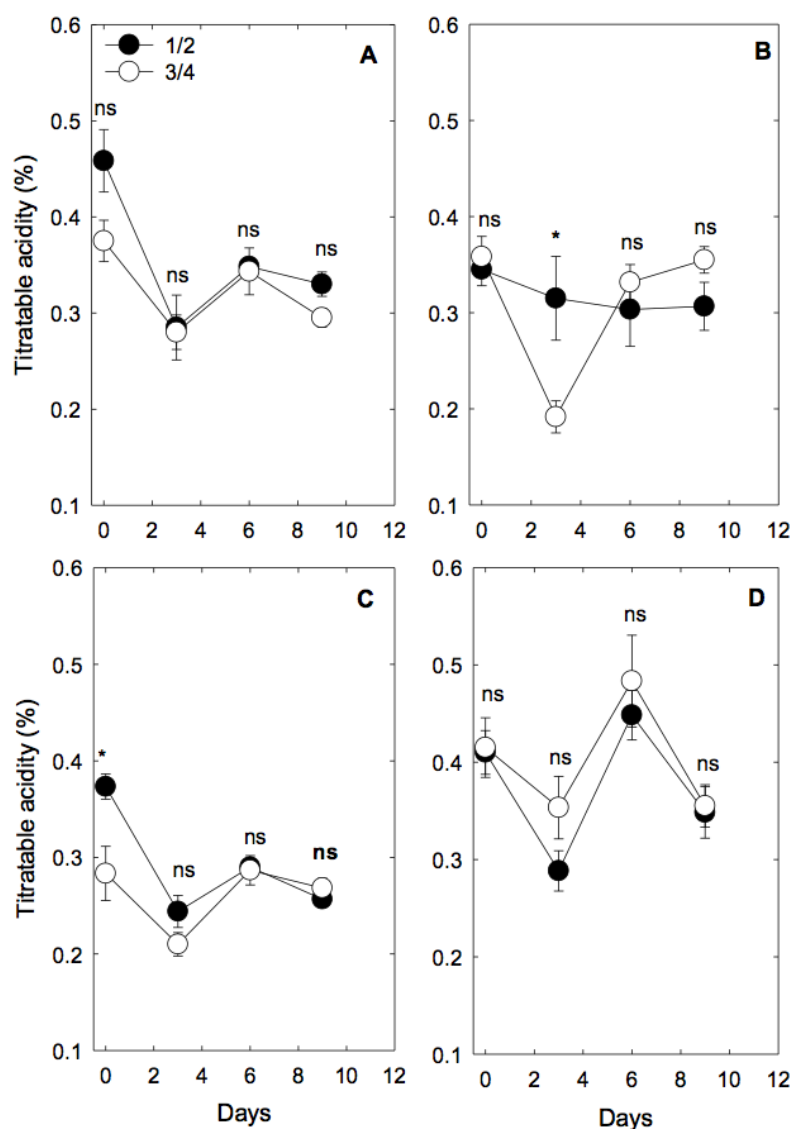


Figure 4. Titrateable acidity in (A) ‘Amarilla’, (B) ‘Castilla’, (C) ‘Chapilla’ and (D) ‘Roja’ Mexican plum fruit after harvest at two ripening stages: 50 % (1/2) and 75 % (3/4) color. Each point represents the mean of six observations and its standard error. *: significant at 0.05 according to the T-test. ns: non-significant.

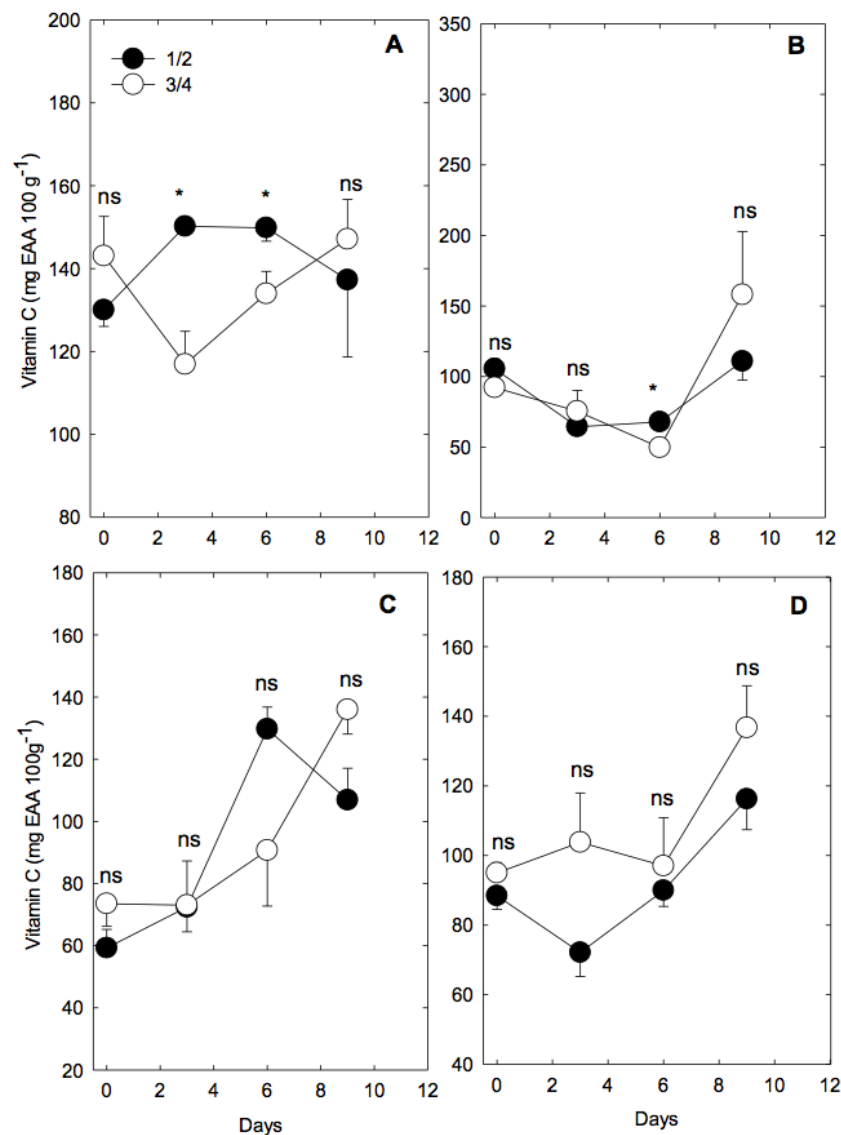


Figure 5. Vitamin C content in (A) 'Amarilla', (B) 'Castilla', (C) 'Chapilla' and (D) 'Roja' Mexican plum fruit after harvest at two ripening stages: 50 % (1/2) and 75 % (3/4) color. Each point represents the mean of six observations and its standard error. *: significant at 0.05 according to the T-test. ns: non-significant.

sixth day (Figure 5A). The 'Chapilla' ecotype had higher vitamin C content, reaching up to 130 mg EAA · 100 g⁻¹ (Figure 5). Bezerra, Gomes, Ferreira, and Freire (2011) reported that, in MexicaFn plum, ascorbic acid increased from 16.1 to 22 mg · 100 g⁻¹ during ripening, attributed to an increase in the synthesis of metabolic intermediates, most likely derived from polysaccharides from cell wall degradation during the ripening process.

Conclusions

Differences in physical, physiological and chemical behavior were determined among the four Mexican plum ecotypes. Differences between harvested ripening stages were detected at the beginning of evaluations but were no longer observed at the end of ripening. The data collected

is initial information for developing post-harvest management technologies for each of the ecotypes.

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