FRUITS 74(4), 194–200 | ISSN 0248-1294 print, 1625-967X online | https://doi.org/10.17660/th2019/74.4.6 | © ISHS 2019

Original article

Phenological stages and fruit development in the Mexican plum ecotype 'Cuernavaqueña' (*Spondias purpurea* L.)

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Summary

Introduction – ***Spondias purpurea* L. or Mexican plum is a fruit tree of Mesoamerican origin with significant potential as a large-scale agricultural crop, yet little information about its phenology and fruit development is currently available.** *Materials and methods* – **The phenological stages that occurred during a one-year cycle of fruit production were assessed in trees of the ecotype 'Cuernavaqueña', along with changes in fruit dimensions, weight (fruit, peel, pulp, and seed), color (L*, C*, and h), and total content of sugars, phenols, and carotenoids.** *Results and discussion* – **The following six phenological stages were easily distinguished: 1) flowering; 2) fruit setting; 3) fruit development; 4) leaf emergence; 5) fruit ripening; and 6) leaf abscission. The fruits presented a double sigmoidal growth curve typical of drupes. During their development, the epicarp color changed from an opaque green (L* = 41.1, C* = 22.6, h = 109.1) to a light and vivid yellow (L* = 45.6, C* = 39.2, h = 87.5), while sugars increased to 79.9 mg g^{-1} f.w. by harvest time. Total phenols in the mesocarp and epicarp decreased to 266.7 and 641.8 µg g^{-1} f.w. respectively, favoring an overall reduction in astringency. In these same tissues, carotenoids increased to 50.8 and 27.0 µg g^{-1} f.w. respectively, facilitating the establishment of a visual harvest index.** *Conclusion* – **The identification of distinct phenological stages along with the growth curve will permit better agronomic management of *S. purpurea* L. Additionally, the chemical composition of its fruits suggests they can supply significant amounts of energy, as well as molecules with a high antioxidant capacity, to the human diet.**

Keywords

jocote, purple mombin, phenological stages, growth curve, antioxidant compounds

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Significance of this study

What is already know on this subject?

- At present, wet-season Mexican plum (*Spondias purpurea* L.), also known as jocote or purple mombin, is mostly cultivated in small backyard orchards, when it has the potential for larger-scale commercial exploitation. However, phenological data and information concerning the physical and chemical changes that occur during the process of fruit development is still very scarce.

What are the new findings?

- Six phenological stages were recognized that could serve as the basis for improving the agronomic management of this species. The growth of wet-season plums followed the double-sigmoidal growth pattern typical of drupes. The fruit was also found to be of considerable nutritional value due to its relatively high content of total sugars, phenols, and carotenoids.

What is the expected impact on horticulture?

- The results obtained can be used to design better agronomic management practices for this particular species. It is hoped that the latter will also favor an increase in the total cultivated surface area devoted to *S. purpurea* L., and aid in the production of better quality fruits.

Introduction

Mexican plum (*Spondias purpurea* L.), also known as jocote or purple mombin, is a fruit tree that is native to southern Mexico and Central America (Miller and Schaal, 2005), where it sometimes constitutes the dominant species in lowland deciduous forests. It can also grow in many different types of soils, as well as at altitudes that range from sea level to 2,000 m (Avitia *et al.*, 2003). Its current distribution spans the western coast of Mexico (beginning in the state of Sonora) and includes the South American countries of Colombia, Brazil, and Peru (Avitia *et al.*, 2003).

The fruits are drupes of different shapes (oblong, round, or oval), weights (4 to 43 g), sizes (15 to 50 mm), and colors (yellow, red, orange, and purple) (Maldonado-Astudillo *et al.*, 2014). Their endocarps are usually thick and fibrous, and their mesocarps have a palatable taste and a pleasant aroma (Morton, 2013). The fruits are rich in minerals (*e.g.* phosphorus, iron), sugars, and antioxidant compounds (*e.g.* phenols, carotenoids, flavonoids) (Solorzano-Morán *et al.*, 2015; Suárez-Vargas *et al.*, 2017; Villa-Hernández *et al.*, 2017), making them attractive as raw materials for the soft drink, confectionery, and dried fruit industries (Kozioł and Macía, 1998).

Mexican plums have a high potential for future commercial development as large-scale agricultural crops. This is due to their relatively low cost of production as *Spondias* trees usually grow well unassisted and are able to adapt to poor and shallow soils – habitats which are typically unfit for most other crops. They are also relatively drought resistant as their defoliation stage coincides with the onset of the dry season, at least in their native regions of growth. This makes them a strategic species for agriculture, especially in places and/or during seasons (*e.g.*, spring) where no other fruit types may be readily available for harvest – a fact that enables their drupes to reach relatively high prices on the market (Ramírez *et al.*, 2008).

S. purpurea L. fruits can be classified into three types: 1) dry-season plums (fruiting from February to May); 2) wet-season plums (fruiting from September to December) and 3) intermediate or mid-season plums (fruiting from June to July) (Avitia *et al.*, 2003, Ruenes-Morales *et al.*, 2010; Álvarez-Vargas *et al.*, 2017). In Mexico the variants that are most often commercially exploited include about 100 different ecotypes from the states of Veracruz (Cruz *et al.*, 2012), Tabasco (Vargas-Simón *et al.*, 2011), Yucatán (Ruenes-Morales *et al.*, 2010), Jalisco (Ramírez *et al.*, 2008), Morelos, and Guerrero (Alia-Tejacal *et al.*, 2012; Cruz *et al.*, 2012; Maldonado *et al.*, 2017). However, despite the regional prominence of this plant resource, research concerning its agronomic management has been relatively scarce, especially in Mexico (Alia-Tejacal *et al.*, 2012).

In the state of Morelos, Mexican plum trees are frequently grown in the wild; otherwise, they are cultivated in small backyard gardens or at larger commercial orchards (Alia-Tejacal *et al.*, 2012). Wet-season plums are typically found in the northern regions of the state, with trees that flower from January to March and fruits that are harvested from September to November. These fruits are usually oval, irregularly-shaped drupes, with smooth, shiny epicarps of a reddish-yellow color and flesh that is acidic but sweet tasting (Álvarez-Vargas *et al.*, 2017). This ecotype is known regionally as 'Cuernavaqueña', and its fruit is generally eaten fresh due to its many organoleptic properties. It is likewise considered to be an important agricultural crop with great potential for further commercial development and economic expansion.

Unfortunately there are, at present, no studies that examine the phenological, physical, or chemical changes that occur during the growth and development of 'Cuernavaqueña'. These changes are important to consider for the adequate planning and management of orchards, which include activities such as pruning, fertilization, irrigation, and the application of suitable growth regulators, among various other tasks. Such actions must always be considered carefully so that they may be conducive to the growth of fruits of an acceptable quality (Opara, 2000). Thus, the objective of this study was to evaluate the different stages and timing of fruit development, as well as the changes that occur in the physical and chemical characteristics that determine fruit quality in the Mexican plum ecotype known as 'Cuernavaqueña'.

Materials and methods

This study was conducted between February 2013 and April 2014 in an eight-year-old orchard of the Mexican plum ecotype known regionally as 'Cuernavaqueña'. This orchard is located in the municipality of Zacualpan de Amilpas, Morelos, Mexico (18°47'48.25"N; 98°46'43.26"W, 1,653 m a.s.l.) and at the time of our sampling, consisted of trees separated by a distance of 4 m which were set into rows 6 m apart. Eleven of these trees were then randomly selected, and in each of them, four different branches were chosen (*i.e.*, one for each cardinal point: N, E, S, and W). All branches contained either developing buds or actual flowers. A phenological evaluation was subsequently performed every 15 days over the course of a year.

From these data, the periods that mostly corresponded to flowering, fruit setting, fruit development, leaf abscission/defoliation, leaf emergence, and harvest maturity, were determined. During such periods, the values for precipitation (mm), maximum and minimum temperatures (including monthly averages), as well as monthly relative humidities, were recorded with the help from local weather stations (IMTA, 2014).

Polar (PD) and equatorial diameters (ED) were taken using a digital caliper (Mitutoyo Co. Ltd.); this was begun in March 2013 (when fruit setting first occurred) and was performed every 15 days in order to determine the kinetics of fruit growth until harvest maturity was reached. Then, a total of 10 fruits were collected from each tree. This was repeated every month from April 2013 onwards, with the fruits being stored inside polyethylene bags for subsequent transport to the Agricultural Production Laboratory in the Faculty of Agricultural and Livestock Sciences at the Universidad Autónoma del Estado de Morelos in Cuernavaca, Mexico.

Once at the laboratory, the total fresh weight (f.w.) and skin color (*i.e.*, L*, C*, and h values) of each fruit were determined. The drupes were then partitioned according to the following three anatomical structures: epicarp (skin or fruit rind), mesocarp (pulp), and endocarp (the thick and fibrous stone). The latter was done in order to determine the total weight of each, in addition to the total sugars (in the pulp), phenols (in both the rind and pulp), and carotenoids present (once again, in both the rind and pulp).

Fruit weight was determined individually using an OHAUS digital scale (0.01 g) while lightness (L*), hue angle (h), and chroma (C*) were averaged from triplicate measurements that were also obtained individually for each fruit. For this, an X-rite spectrophotometer (Mod. 3960, NV, USA) was used.

Total sugars were quantified according to the methodology described by Solorzano-Morán *et al.* (2015) and which is here briefly outlined as follows: First, sugars were extracted using ethanol; the mixture was then evaporated and the residue dissolved in dH_2O. This reconstituted residue was subsequently made to react with anthrone solution in the presence of sulfuric acid, and the absorbance read at 600 nm using a Genesys 6 spectrophotometer (Milton Roy, NY, USA). A glucose calibration curve was then used to calculate the concentration of total sugars.

Total phenols were quantified using the Folin-Ciocalteu method as reported by Waterman and Mole (1994) with the modifications recommended by Solorzano-Morán *et al.* (2015) which are described here as follows: Samples of finely chopped epicarp and pulp were first mixed inside a cold methanol solution (80% v/v). They were then homogenized and filtered. A sample of this new solution was made to react with Folin-Ciocalteu reagent in the presence of sodium carbonate (alkaline medium), incubated, and the absorbance read at 760 nm using the same spectrophotometer that was mentioned previously. A calibration curve based on tannic acid was then used in order to calculate the concentration of phenols.

Total carotenoids were determined according to the methodology reported by Alia-Tejacal *et al.* (2002) and Solorzano-Morán *et al.* (2015), with some modifications. In addition to the total (*i.e.*, combined) concentrations in both epicarp and pulp, individual values were determined for each of these tissues. The procedure is briefly described here as follows. Samples from either pulp or epicarp were first mixed with acetone, homogenized, filtered, and then placed inside a separating funnel, to which hexane and dH_2O were added. The mixture was stirred and allowed to stand until phase separation occurred (the upper phase containing the carotenoids dissolved in hexane; the lower phase containing the acetone and water). The aqueous phase was subsequently discarded, and the organic phase was washed several times using dH_2O in order to remove all traces of acetone. Afterwards, a 4N solution of NaOH was added in order to saponify any oils remaining in the extract. Next, the sample was passed through a filter paper containing a layer of anhydrous sodium sulfate so as to remove any residual water. The absorbance of the filtrate was read at 452 nm using the same Genesys 6 spectrophotometer. From the data obtained, total carotenoids were determined using β-carotene in hexane according to the following equation:

$$Total\ carotenoid\ content = \frac{A \times volume\ (mL) \times 10^4}{A_{1cm}^{1\%} sample\ mass\ (g)}$$

where A = absorbance; volume = total volume of the extract obtained; and $A_{1cm}^{1\%}$ = 2,580 β-carotene in hexane. The total carotenoid content was expressed as mg 100 g^{-1} f.w.
With these data, an analysis of variance and subsequent comparison of means using the Tukey test ($P \leq 0.05$) were performed according to statistical procedures in SAS® V.9.2 software (Castillo, 2011).

Results and discussion

Environmental conditions

Precipitation in the region of fruit collection varied from 1.8 to 37.2 mm during the first four months of 2013. By May, however, average values had increased to 82.8 mm, and from the start of the rainy season in June until its end in October, monthly values ranged from 105.8 to 298.8 mm. Later, during the dry season (from November 2013 to April 2014) average precipitation was less than 37.2 mm per month (Figure 1).

Average monthly temperatures ranged from 17.8 to 24.8 °C, with a maximum occurring in April (Figure 1). By contrast, the single lowest temperature value (*i.e.*, absolute minimum) occurred during March and was 2.3 °C; however, no chilling injury was observed in *S. purpurea* L. fruits. With the exception of this apparent anomaly, the temperatures in the months that followed failed to drop below 5.3 °C (Figure 1). Interestingly, Cruz *et al.* (2012) report that *S. purpurea* grows best in climates with average monthly temperatures

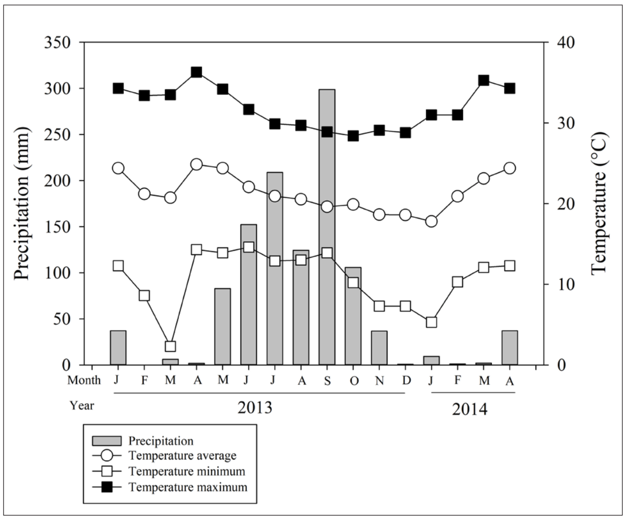

FIGURE 1. Climatological conditions during the development of *S. purpurea* L. fruit of the ecotype 'Cuernavaqueña' during the 2013–2014 production cycle in Zacualpan de Amilpas, Morelos, Mexico.

between 20 and 29 °C, with absolute minimums needing to be >4 °C. This suggests that 'Cuernavaqueña' can endure temperatures that fall well below the range normally required by this species.

Relative humidity was highest during the period of maximum precipitation (July to October) where it ranged from 72.8 to 85.9% (Figure 1). However, no study has yet contemplated the influence of relative humidity on the physiology and quality of *S. purpurea* fruit, an aspect which must be addressed in future works.

Phenology

Six phenological stages could easily be distinguished in Mexican plum trees of the ecotype 'Cuernavaqueña'. These were determined over the course of a one-year cycle of fruit production (February 2013 to April 2014) and were separated as follows: 1) flowering (February to March); 2) fruit setting (March); 3) fruit development (April to October); 4) leaf emergence (April to May); 5) fruit ripening or consumption maturity (September to November); and 6) leaf abscission or defoliation (December to March) (Figure 2). However, in ecotypes from Yucatán (a state in south-east Mexico), only five phenological stages occur during the year. These include: 1) flowering; 2) fruiting; 3) fruit ripening (*i.e.*, consumption maturity); 4) foliation; and 5) defoliation (Ruenes-Morales *et al.*, 2010). These stages, however, may vary in length and ultimately depend on the ecotype analyzed.

Furthermore, under the prevalent climatic conditions of Tabasco (also in south-east Mexico) Vargas-Simón *et al.* (2011) report leaf abscission to occur from January to February, foliation from May to December, and both flowering and fruiting from January to May. On the other hand, in the state of Nayarit (western Mexico), Salazar and Becerra (1994) describe eight separate phenological stages over the course of a single year. These are: 1) flowering (February to March); 2) fruit growth (March to June); 3) fruit ripening or consumption maturity (June); 4) foliation (June to October); 5) root growth (August to October); 6) floral differentiation (August to November); 7) defoliation (October to May); and 8) rest (November to February). Such differences are likely a reflection of the varied environmental conditions (*e.g.*, precipitation and temperature) present in the specific areas of study.

Physical and chemical changes during fruit growth and development

Statistically significant differences were found across all stages of fruit development in Mexican plums of the ecotype 'Cuernavaqueña'. This was true for all chemical and physical characteristics analyzed, according to the results of *F*-tests (Figures 2–4).

Polar and equatorial diameters

Fruit growth in 'Cuernavaqueña' lasted 240 d on average. The latter included both fruit setting in March and harvest-time in October (Figure 2). This period, however, contrasts sharply with the 70 d reported in 'yellow Gorda' under the prevailing climatic conditions of the state of Nayarit (also in Mexico). In fact, the growth period of the latter would still be significantly shorter even if one were to include the flowering stage as well (Salazar and Becerra, 1994). On the other hand, Baraona and Rivera (1995), Pereira *et al.* (2003), and Dantas *et al.* (2016) all report somewhat comparable growth periods (124–182 d total) from the time of anthesis until harvest maturity. Such studies encompass both fruit cultivated in Costa Rica (Heredia province) as well as in Brazil (Bananeiras municipality, Paraíba state). It must be clarified, however, that none of them specify the ecotypes of Mexican plum analyzed, except for Dantas *et al.*, 2016, which do mention a *S. tuberosa*-*S. purpurea* L. hybrid known locally as "umbugueleira". Nevertheless, their findings certainly imply that the fruits of 'Cuernavaqueña' differ considerably from those cultivated in other regions of Mexico (*i.e.*, Nayarit) and the world (*i.e.*, Costa Rica, Brazil). However, the longer developmental period observed in 'Cuernavaqueña' was almost certainly also influenced by the specific environmental conditions (*e.g.*, 10.2–14 °C temperature) present during the course of our study (Figure 1).

'Cuernavaqueña' fruits also exhibited a double sigmoidal pattern of growth (Figure 2). For instance, linear growth was first evident in both polar (PD) and equatorial diameters (ED) from the period encompassing the months of March and May. Growth would then slow down considerably from June to August, before increasing again from September to October, reaching final values of 43.7 and 34.9 mm, respectively (Figure 2). Such is the characteristic growth pattern of fruits commonly classified as drupes, which include the European plum (*Prunus domestica*), the cherry (*Prunus cerasus*), the grape (*Vitis vinifera*) and the olive (*Olea europaea*) (Diaz, 2002). This contrasts with the simple sigmoidal pattern used to model the growth of Mexican plums from Brazil, where values of 32.17 and 24.73 mm were obtained for PD and ED respectively.

Such differences in results probably stem from the fact that, in our study, the period of evaluation was considerably longer (240 d *vs.* 119 d), and as a result, a double sigmoidal growth curve could more easily be discerned. In this sense, the fastest growth rates coincided with the phenological stages characterized by an absence of leaves from trees (Figure 1), whereas subsequent episodes of either slow or slightly faster growth coincided with periods of full foliation (Figure 2). Such behavior is likely governed by the supply of carbohydrates to the developing fruits, which are necessary if further growth is to occur (Jackson and Looney, 1999). Other studies report an analogous pattern (Salazar and Becerra, 1994) and similarly suggest that growth can be supported by the water and carbohydrate reserves present in the stems of *Spondias* trees (Vargas-Simón *et al.*, 2011).

Fruit weight

Average values for this variable fluctuated between 10.6 and 11.1 g from March to May (Figure 3A). By August, the fruit had attained 50% of their final weights, and by October, they had reached 30.6 g on average (Figure 3A). Such values exceed others reported for several varieties of Mexican plum cultivated in Ecuador (9.0 to 18 g) (Macía and Barfod, 2000) but are otherwise comparable to those of *S. purpurea* L. from warmer climates (35.8 to 43 g) (Ramírez *et al.*, 2008; Alia-Tejacal *et al.*, 2012).

Total fruit weight is, of course, influenced by the values of its individual components (*i.e.*, the weight of the epicarp, mesocarp, and endocarp tissues, see Figure 3B). For example, the weight of the exocarp was also constant from April to August (4.0 g to 4.5 g) but experienced a two-fold increase in its average value from September to October before

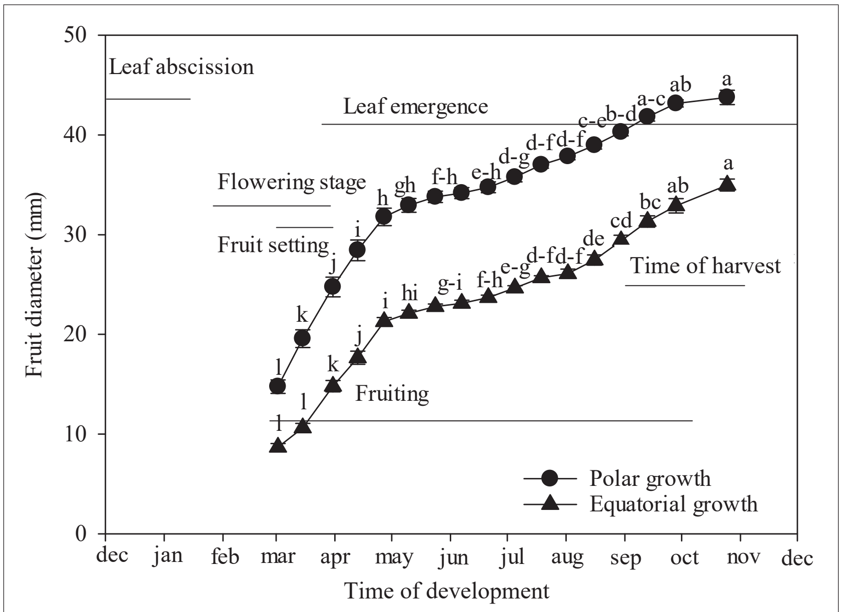

FIGURE 2. Phenological stages and kinetics of growth in the polar (●) and equatorial (▲) diameters of *S. purpurea* L. fruits of the ecotype 'Cuernavaqueña' from Zacualpan de Amilpas, Morelos, Mexico. Each point represents the mean of 40 measurements ± standard error. Identical letters among sampling dates indicate statistical similarity according to the Tukey test ($P \leq 0.05$).

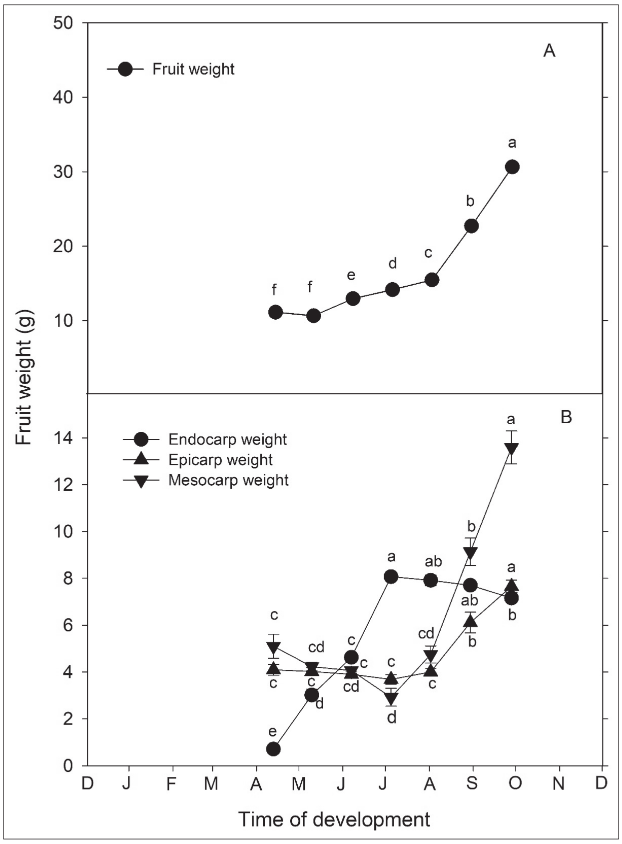

FIGURE 3. The weight of *S. purpurea* L. fruits (A) and individual anatomical structures (B) during a one-year cycle of fruit production in Zacualpan de Amilpas, Morelos, Mexico. Each point represents the mean of 10 determinations ± standard error. Different letters among sampling dates indicate statistical difference according to the Tukey test ($P \leq 0.05$).

finally peaking at approximately 8 g by the end of this period (Figure 3B). Similarly, the weight of the mesocarp varied little from April to August (3 to 5 g) before increasing to 14 g towards the end of October (Figure 3B). On the other hand, the weight of the endocarp behaved somewhat differently, increasing steadily from April to July (0.7 g to 8.0 g) before stabilizing in the months that followed (7.1 to 7.9 g, see Figure 3B). In peach (*Prunus persica* L. Batsch), a fruit with a double sigmoidal growth pattern, total weight during the first stage of development is mostly influenced by the growth of its endocarp and mesocarp. Subsequently, during the second stage, the endocarp reaches its maximum value while the mesocarp continues to grow, albeit slowly. Then, during the third stage of development, the pulp attains its maximum weight (Génard and Bruchou, 1993). This pattern strongly resembles the one observed in this study.

By October (*i.e.*, the period corresponding to fruit ripening), the endocarp, epicarp and mesocarp constituted 27, 25.2, and 47.8% of the total fruit weight, respectively. This means that the edible portion of the fruit, which consists of both the mesocarp and epicarp, accounted for 73% of its total weight, a value that is lower than the one reported by Vargas-Simón *et al.* (2011) for dry-season plums from the State of Tabasco (in Mexico). Similarly, in Mexican plums from Brazil, the edible portion was reported to constitute up to 83% of the total mass of the fruit (Cunha-Filgueiras *et al.*, 2001). On the other hand, values of 66% have been reported by Kozioł and Macía (1998) in *S. purpurea* L. from Ecuador.

Lightness (L), chromaticity (C*), and hue angle (h)*

Mexican plums of the ecotype 'Cuernavaqueña' were a dull green (L* = 41.1, C* = 22.6, h = 109.1) at the beginning of our analysis (April) and remained so until August, when the color became more vivid and increased in lightness (L* = 44, C* = 26.3, h = 110.7). Nevertheless, by October, the fruit had

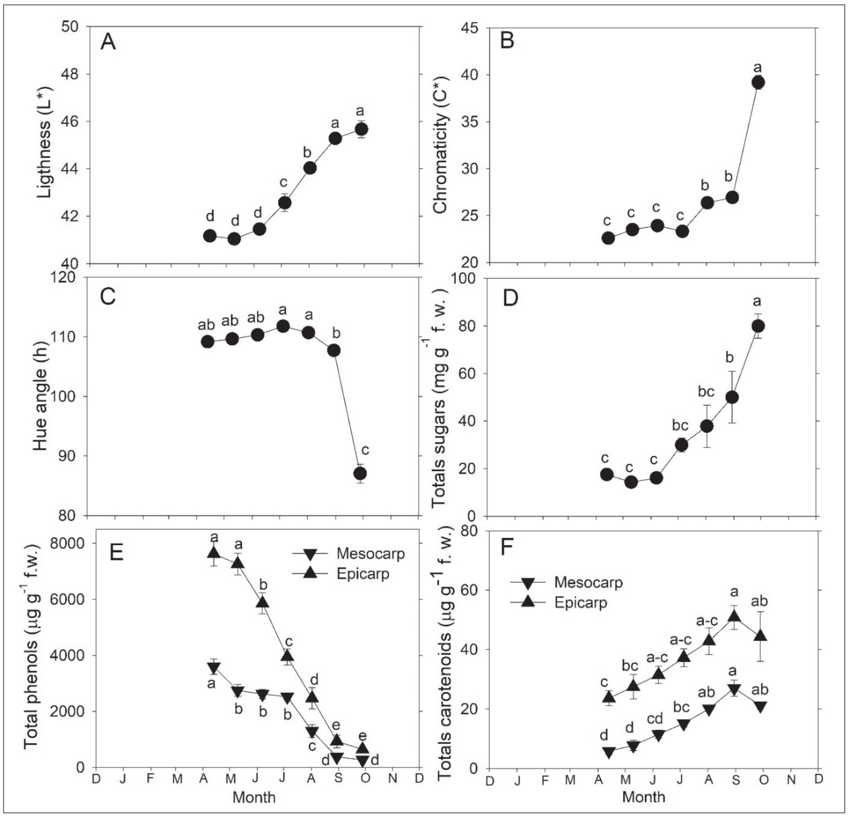

FIGURE 4. Color parameters in the epicarp: A) Lightness (L*); B) chromaticity (C*); C) hue angle (h); and the concentration of total D) sugars; E) phenols; and F) carotenoids during the growth of *S. purpurea* L. fruits of the ecotype 'Cuernavaqueña'. Each point represents the mean ± standard error. Different letters among sample points indicate statistical difference according to the Tukey test ($P \leq 0.05$).

turned a light and vivid yellow (L*=45.6, C*=39.2, h=87.5) (Figure 4 A–C). By comparison, hue angle in wet-season plums at the 'turning' stage of ripening (*i.e.*, where 75% of the surface is green) have been reported as 100.4 ± 3.2, whereas those of mature fruit (where 25% of the fruit surface is green) are usually 46.2 ± 5.6 (Bautista-Baños *et al.*, 2003). As a result, the fruits that were harvested in October were most likely at an intermediate stage of ripening (in other words, at a stage between 'turning' and 'mature').

Total sugars

From April to June, the content of total soluble sugars fluctuated between 14.3 and 17.5 mg g^{-1} f.w. (Figure 4D). By July, average values had increased to 29.9 mg g^{-1} f.w., and by October (*i.e.*, harvest time) had reached 79.9 mg g^{-1} f.w. (Figure 4D). In this case, the changes that were observed in the mesocarp and exocarp in terms of weight correlated well with the biggest increase in the content of these sugars (r = 0.92**). Such molecules are therefore the most likely sources of energy during the final stages of fruit development, a situation that is similar to the one in peach (*Prunus persica*) (Liu *et al.*, 1999). Interestingly, when 'Cuernavaqueña' fruits are harvested with 7 to 8 mg g^{-1} of total sugars in their pulp, they can still attain values of 176 to 182 mg g^{-1} f.w. after six days of storage, suggesting that an adequate flavor is actually reached after harvest (Maldonado-Astudillo *et al.*, 2014).

Total phenols

The content of these decreased steadily with time during fruit development (Figure 4E). For instance, phenol concentrations in the epicarp – which averaged 7,630.4 µg g^{-1} f.w. in April – dwindled to just 641.8 µg g^{-1} f.w. by October (Figure 4E). A similar trend occurred in the pulp, where the 3,600 µg g^{-1} f.w. present during April had instead become 266.7 µg g^{-1} f.w. by October (Figure 4E). Hence, a 91.6 to 92.6% decline in the concentration of these compounds occurred during this period. Even though the phenol content of the skin was initially two times higher than the one in the pulp (*i.e.*, from April to June), this would later change to just 0.5 times during subsequent months (Figure 4E). Thus, total phenols (epicarp + mesocarp) averaged 908.5 µg g^{-1} f.w. by harvest time in late October (see Figure 4E). This value, however, has the potential to decrease even further as postharvest concentrations between 380 and 520 µg g^{-1} f.w. are not uncommon (Maldonado-Astudillo *et al.*, 2014). Still, Mexican plums can be regarded as important sources of such compounds.

The physiological role of phenols is varied and often includes growth, resistance to pathogens or disease, and pigmentation (Lattanzio *et al.*, 2008). Although a decrease in these compounds during fruit development (and into physiological maturity) might at first appear desirable because of a concomitant decrease in astringency (Fawole *et al.*, 2013), many consumers are often more interested in foods that contain molecules with beneficial health effects. Hence, a higher content of polyphenols may actually be more marketable in light of their established antioxidant properties (Rinaldo *et al.*, 2010).

Total carotenoids

The content of these increased in both the epicarp and pulp during fruit development (Figure 4F). Carotenoids were, however, always more abundant in the epicarp (23.6 µg g^{-1} f.w. in April; 50.8 µg g^{-1} f.w. in October) than in the mesocarp (5.83 µg g^{-1} f.w. in April; 27 µg g^{-1} f.w. in October), with maxima occurring during the months of September and October (Figure 4F). The latter also coincided with the emergence of yellow (h = 87) in the exocarp or skin. This increase in carotenoids was most likely accompanied by a decrease in chlorophyll.

In the form of pro-vitamin A (a light-absorbing molecule and light shield) carotenoids can have varied physiological effects on humans. They can also exert some influence over the outcome and prevention of certain health conditions such as macular degeneration, cataracts, cardiovascular disease, and various forms of cancer (Valero and Serrano, 2010). In this regard, 'Cuernavaqueña' fruits can be considered as excellent sources of such compounds, especially compared to other tropical fruits like the banana (9.4–27.8 µg g^{-1} f.w.), the pineapple (1.36 µg g^{-1} f.w.), the papaya (2.32–5.98 µg g^{-1} f.w.) or the mango (9–92 µg g^{-1} f.w.) (Thanaraj and Terry, 2011).

Conclusion

Mexican plums of the ecotype 'Cuernavaqueña' have the longest growth period of any variant of *S. purpurea* L. known to date, a fact that can be partly explained by the specific climatic conditions present in its native region of growth. Six different phenological stages can easily be distinguished over the course of a single year, and the resulting fruits are characterized by a double sigmoidal growth pattern that is typical of drupes. The final edible portion (epicarp and mesocarp) can comprise up to 73% of the total fruit weight and contains significant amounts of sugars, phenols, and carotenoids. This makes *S. purpurea* L. fruits important sources of both energy and antioxidant molecules, especially when compared to other species of tropical origin. However, future studies should aim to clarify the influence of relative humidity on the physiology and quality of this important Mesoamerican crop.

Acknowledgments

The first author (J.E. Alvarez-Vargas) would like to thank CONACyT for the financial support provided to her over the course of her postgraduate studies. All of us would like to thank SEP-PROMEP for the funds used to finance this study, as well as the technical assistance provided by Alyn Mariana Palacios Sosa M.Sc. Lastly, we would like to thank Leonardo Castillo Pelayo B.Sc. (Hons.), for his assistance during the revision of the English-language manuscript.

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Received: Apr. 29, 2018
Accepted: Apr. 29, 2019