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Postharvest quality and physiological changes in five ecotypes of *Spondias purpurea* L. harvested at three distinct maturity stages

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Abstract: The fruit of *Spondias purpurea* L. is well accepted from different regions of Latin America. In many cases, however, their postharvest quality and physiological behavior have not been adequately studied. These aspects were therefore examined in five commercially grown ecotypes from Mexico. To this end, samples of green-, half ripe-, and ripe-harvested fruit were stored at 25 °C (60 % RH) for 5 d – with several indicators of quality and postharvest behavior periodically assessed. Four out of the five ecotypes examined produced drupes that were large (> 15 g in 'Costeña', 'Amarilla', 'Morada', and 'Costilluda'). On the other hand, large differences in weight loss (5–21 %) and in the total soluble solids of ripe fruit (9–17 %) were apparent, as was a 9.3 % increase in the weight of drupes when they transitioned from the green to the half ripe stage on trees, suggesting that harvesting should take place during this period. Increments in the production of CO_2 and ethylene were both associated with a shortening of postharvest life. Based strictly on firmness, the ecotypes most likely to resist postharvest handling were 'Morada' and 'Conservera'. Best global quality on the other hand, belonged to 'Amarilla' and 'Costeña'.

Index terms: Mexican plum, ripening, respiration, ethylene, climacteric pattern.

Qualidade pós-colheita e alterações fisiológicas em cinco ecótipos de *Spondias purpurea* L. colhidos em três estádios de maturação

Resumo: O fruto de *Spondias purpurea* L. é bem aceito em diferentes regiões da América Latina. Entretanto, a qualidade e o comportamento fisiológico pós-colhei-

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ta nesta fruta não têm sido bem estudados. Portanto, alguns destes aspetos foram avaliados em cinco dos ecótipos cultivados comercialmente no México. Amostras de frutas colhidas em estado verde, meio madura e madura foram armazenadas a 25 °C (60 % UR), por 5 dias, durante os quais foram avaliados indicadores de qualidade e o comportamento pós-colheita. Quatro dos cinco ecótipos em avaliação apresentavam drupas grandes (> 15 g): 'Costeña', 'Amarilla', 'Morada' e 'Costilluda'. As maiores diferenças obtidas em perda no peso (5–21%) e nos sólidos solúveis totais da fruta madura (9–17%) são só aparentes, já que houve aumento de 9,3% no peso das drupas quando estas passam da fase verde a meio madura nas árvores, sugerindo que a colheita deve acontecer neste estádio. Incrementos na produção do CO_2 e do etileno foram associados à diminuição na longevidade pós-colheita. Fundamentados, somente na firmeza da fruta, os ecótipos com a maior possibilidade de resistir ao manuseio pós-colheita foram o 'Morada' e o 'Conservera'. Entretanto, em geral, a melhor qualidade corresponde ao 'Amarilla' e ao 'Costeña'.

Termos para indexação: ciriguela, amadurecimento, respiração, etileno, climatérico.

Introduction

The genus *Spondias* consists of about 15 species of trees and shrubs native to both tropical Asia and America – though some are also found in certain regions of Africa. Three of these (*Spondias purpurea* L., *S. mombin* L., and *S. radkoferi* J. D. Smith) originate from Mexico, where they are particularly abundant in coastal areas, as well as in the Southeast (MALDONADO et al., 2014). In fact, the Gulf coast and states of Guerrero and Morelos harbor diverse populations of *S. purpurea* L. (both wild and cultivated) – a species which many locals have come to rely on economically (AVITIA et al., 2003; ALIA et al., 2012; MALDONADO et al., 2017). The plant is also well adapted to different temperatures, altitudes, and soils, a fact that has helped maintain its cultivation costs low.

The fruit of *S. purpurea* L. – commonly known as Mexican plum, jocote, or jobo in Mexico and as Lapa, Job, Moyo, Sta Roseno, Jismoyo, and De Cocer in other countries – is widely consumed in many regions of Latin America and the Caribbean (MOHAMMED et al., 2019), and has been since pre-Hispanic times (RUENES et al., 2010). The drupe is varied in shape (ovoid, round, or oblong), size (20–50 mm in longitudinal diameter), and weight (4–43 g) – possessing both a thick, fibrous endocarp as well as a pleasantly flavored/aromatic flesh (sweet but with a slightly acidic aftertaste, similar to that of a plum). At maturity, the thin, waxy epicarp can attain one of several colors, including yellow, orange, red, or purple (MALDONADO et al., 2014). The fruit is also a good source of carbohydrates as well as of different phytonutrients, such as vitamin C, carotenoids, and polyphenols – all of which serve to enhance its antioxidant capacity (KOZIOL; MACIA, 1998, BESERRA et al., 2011).

Most commercial varieties are harvested when the epicarp is still green or has just started to turn. This both increases postharvest life and ensures that transportation times are sufficient (the fruit of *S. purpurea* L. is highly perishable). However, the influence of maturity stage at harvest on subsequent physiological behavior has not been adequately studied, except in a few instances (PÉREZ et al., 2004; OSUNA et al., 2011; MALDONADO et al., 2014). Additionally, both climacteric (SAMPAIO et al., 2008; MONTALVO et al., 2011; OSUNA et al., 2011) and non-climacteric (PÉREZ et al., 2004) patterns of respiration are reported, leading to conflicting interpretations. The objective of this work then, was to evaluate the postharvest behavior of five ecotypes of *S. purpurea* L. cultivated in the Mexican states of Morelos and Guerrero. These ecotypes were selected based on the number of studies that detail their commercial cultivation in Mexico, making them good candidates for subsequent experiments on postharvest handling.

Material and methods

Biological material

Five ecotypes of *S. purpurea* L. fruit were collected from different locations in the Mexican states of Morelos and Guerrero (see Table 1, Figure 1); approximately 200 fruits of each ecotype were harvested and only drupes that were free from physical and pathological damage were selected. These were then stored at room temperature for 12 h (25 ± 2 °C, 60 % RH) in order to eliminate field heat, before being washed, disinfected (200 mg L^{-1} sodium hypochlorite) and dried with absorbent paper. Subsequently, and on later assessments, maturity stage was determined by following a visual scale. This scale was exclusively based on external (i.e. epicarp) coloration and included a green (100–75 % green), a half ripe (50 % green), and a ripe (0–25 % green) phase (Figure 1). The drupes were then stored at 25 ± 2 °C (60 % RH) for 5 days, during which time, a series of quality and physiological assessments were performed (see sections below).

Initial characterization

A digital vernier (TRUPER®, Tepotzotlán, Edo. Mex., México) was used to measure longitudinal (LD) and transverse diameters (TD); shape indices (SI) were obtained by calculating the LD/TD ratios. Weight was measured on an OHAUS® digital scale (Model V11P15, Ohaus Corp., Pine Brook, NJ, USA); firmness

Table 1 - Geographic location of the five ecotypes of *S. purpurea* L. evaluated.

Ecotype	State in Mexico	Municipality	Latitude N	Longitude W	Altitude (m)
'Costilluda'	Morelos	Axochiapan	18°28'02"	98°43'34.7"	1016
'Costeña'	Guerrero	Acapulco	17°4'37"	99°44'28.9"	480
'Conservera'	Guerrero	Huitzuco	18°21'14.7"	99°24'52.3"	882
'Morada'	Guerrero	Cocula	18°14'14.2"	99°39'17.8"	626
'Amarilla'	Guerrero	Tepecoacuilco	18°17'56.2"	99°26'13.5"	881

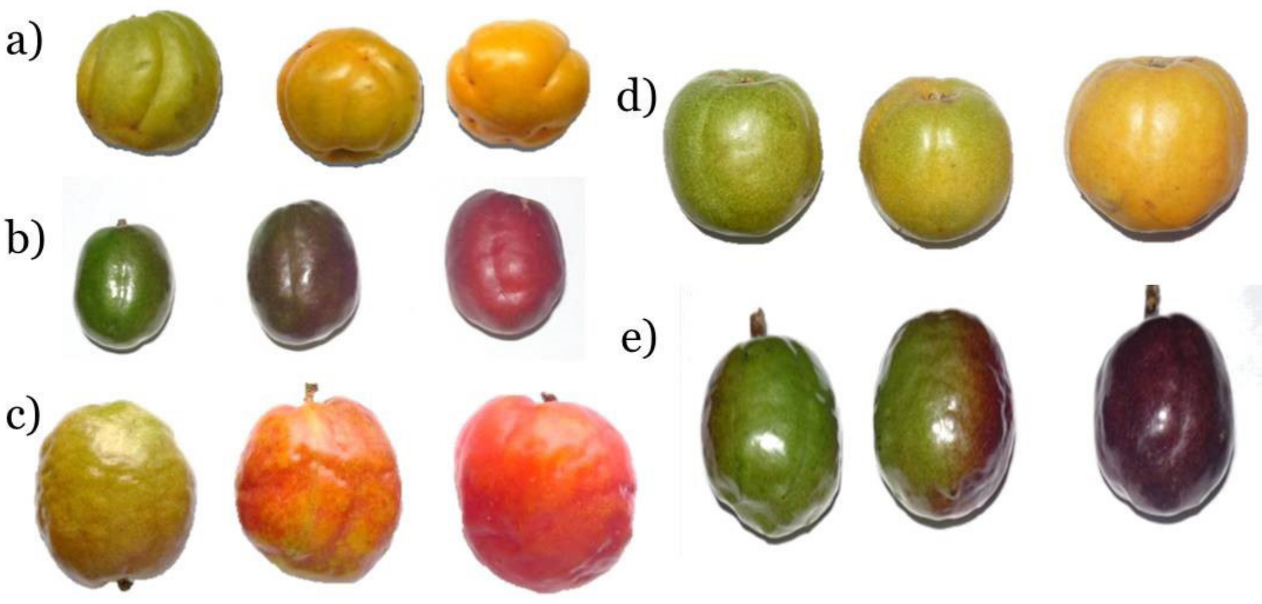

Figure 1 - Examples of fruit from the five ecotypes of *S. purpurea* L. evaluated. a) 'Costilluda' b) 'Conservera' c) 'Costeña' d) 'Amarilla', and e) 'Morada'. In all cases, representative images of the green, half ripe, and ripe stage are presented.

with a digital texturometer (Chatillon DF250 [0.6 mm height x 0.7 mm base cone tip]; AMETEK Inc., Berwyn, PA, USA). For the latter, two opposing points on a fruit's equatorial axis were selected; the force necessary to penetrate the epicarp was then registered and expressed in Newtons (N).

Variables measured during ripening

Respiration and ethylene production were quantified using a static method (ALIA et al., 2005). For this, a single fruit was placed inside a container of known volume (airtight and made of glass), and after 1 h, a 6 mL sample of headspace air was extracted (Vacutainer® glass tube; Becton-Dickinson and Co., Franklin Lakes, NJ, USA); 1 mL was then injected into a Hewlett-Packard® 5890 Series II gas chromatograph (J&W Scientific, Folsom, CA, USA) equipped with a PoraPLOT Q fused-silica column (Agilent Technologies, Mexico). Injector, oven, and detector temperatures (TCD for CO_2; FID for ethylene) were 150 °C, 80 °C, and 150 °C, respectively, with helium as the carrier gas (2 mL min^{-1} flow rate). The absolute calibration method, along with high purity standards (460 mg L^{-1} for CO_2, 400 mg L^{-1} for ethylene; Grupo INFRA®, Naucalpan, Edo. Mex., Mexico), were used for these quantifications.

Accumulated weight loss (WL) was calculated by subtracting final measurements from initial ones (OHAUS® digital balance, Parsippany, NJ, USA) and expressing the results as percentages of the latter (i.e. of initial weight). The epicarp color at two opposing sides of a fruit's transverse diameter was also measured (X-rite® 3690 spec., Grand Rapids, MI, United States) and reported in terms of lightness (L *), chromaticity (C *), and hue (h) (NEGUERULA, 2012). Firmness was, again, evaluated as described previously. The AOAC's potentiometric method 981.12 (AOAC, 1990) was used to determine titratable acidity (TA) in homogenized pulp samples; total soluble solids or TSS (PAL-1 refractometer, Atago® Co. Ltd., Tokyo, Japan) as well as pH (digital pH Meter) were evaluated as described in ALIA et al. (2012). The Taste index (TI) could then be obtained by calculating a fruit's TSS/TA ratio.

For non-destructive variables (i.e. dimensions, color, weight and weight loss, respiration rate, ethylene production), the experimental unit employed consisted of one fruit and five repetitions (using sampling without replacement every 12 h for 5 d). For firmness, the experimental unit selected was two fruits and six repetitions (this time, using sampling *with* replacement every 12 h for 5 d); lastly, for chemical measurements (TSS, TA, pH) the experimental unit used was two fruits and three repetitions (again, sampling *with* replacement every 12 h for 5 days).

Statistical analysis

PASW v.19 software (IBM SPSS statistical package; Chicago, IL, USA) was used to perform analyses of variance and comparisons of means (Tukey method; $P \leq 0.05$), SAS v.9.4 (SAS Institute, Cary, NC, USA; Castillo, 2011) to run factorial design, and SigmaPlot v.12 (Systat Software, Inc., CA, USA) to generate the graphs.

Results and Discussion

Physical characteristics at harvest

Fruit weight varied from 13–33 g; maximum weight and dimensions were found in 'Costeña', followed by those in 'Amarilla', 'Morada', 'Costilluda', and 'Conservera' (Table 2). According to the classification of BOSCO et al. (2000), only 'Conservera' produced medium-sized fruit (i.e. 12–15 g range, all others were large [> 15 g]). Fruit shape in the former ecotype was also ellipsoidal (shape index [SI]=1.25), whereas it was oblong in 'Morada' and 'Costeña' (SI=1.11–1.13), and more or less round in 'Amarilla' and 'Costilluda' (SI close to 1.0). Prior studies suggest ovate forms to be more common (PÉREZ et al., 2008; LIRA et al., 2010); however, SI values close to 1.0 are preferred (at least for industrial purposes) due to the ease of cleaning and processing (CHITARRA; CHITARRA, 2005).

Weight and firmness were the only parameters significantly affected by maturity stage at harvest (Table 2). Weight, for instance, increased by 9.3 % (2 g) when fruit transitioned from the green to the half ripe stage on trees, while no net gain was apparent in already-ripe specimens. As Mexican plums (like any other drupes) exhibit a double sigmoidal growth curve, increments like these must occur towards the end of phase III, when both mesocarp and endocarp are still growing (ALVAREZ-VARGAS et al., 2019). Thus, to improve yields, *S. purpurea* L. must be harvested during its half ripe stage. Green-harvested fruit on the other hand, was firmer than both half ripe and ripe samples (firmness decreased proportionally to maturity stage on trees), with the firmest drupes belonging to 'Morada' (10.4 N) and the least to both 'Costeña' and 'Conservera' (7.0 N) (Table 2).

Table 2 - Physical characteristics in the green-, half ripe-, and ripe-harvested fruit of *S. purpurea* L. evaluated.

	Studied Factors	Weight (g)	Longitudinal diameter (LD, mm)	Transverse Diameter (TD, mm)	Shape index (LD/TD ratio)	Firmness (N)
Ecotype	'Amarilla'	26.41 b	36.14 b	34.83 b	1.04 c	7.02 c
	'Conservera'	12.74 e	31.92 c	25.48 d	1.25 a	7.4 bc
	'Costeña'	32.72 a	41.83 a	37.18 a	1.13 b	6.97 c
	'Costilluda'	18.41 d	32.48 c	31.96 c	1.02 c	7.81 b
	'Morada'	23.35 c	36.71 b	33.10 c	1.11 b	10.41 a
	MSD	2.35	1.54	1.65	0.05	0.65
Maturity stage	Green	21.39 b	35.34 a	31.80 b	1.12 a	10.14 a
	Half-ripe	23.41 a	36.16 a	32.96 a	1.10 a	7.91 b
	Ripe	23.38 a	35.96 a	32.77 ab	1.10 a	5.72 c
	DMS	1.56	1.02	1.09	0.03	0.43
	CV	10.08	4.2	4.93	4.49	8.76
	E*RS	***	ns	ns	ns	***

Different letters within each column represent significantly different values according to Tukey's HSD (P≤0.05). SMD = significant minimum difference; CV = coefficient of variation; ns = not significant; *** = significant at P≤ 0.001.

Postharvest physiological and quality changes CO_2 and ethylene

In 'Conservera' and 'Costilluda', peak respiration and ethylene production ranged from 128-202 mg CO_2 kg^{-1}h^{-1} and from 172-382 µL C_2H_4 kg^{-1}h^{-1}, respectively, while in 'Morada', 'Amarilla', and 'Costeña' they varied from 75-107 mg CO_2 kg^{-1}h^{-1} and from 150-171 µL C_2H_4 kg^{-1}h^{-1}. In horticultural commodities, both are good indicators of postharvest life – with the release of vital heat from respiration often being used to calculate the refrigeration tonnage required for storage and cooling (mg CO_2 kg^{-1}h^{-1} x 61.2 = Vital heat in kcal· 1000 kg^{-1}h^{-1}) (KADER, 2002). In this study, the magnitude of the two processes correlated well with postharvest life. For instance, fruit quality (as estimated by overall appearance, firmness, and flavor) lasted longer in 'Costeña' (10 d) than in 'Conservera' (5 d). Such results are congruent with an assignment of "highly perishable" to fruit of *S. purpurea* L. – at least as defined by Kader's classification of agricultural commodities (KADER, 2002).

For most ecotypes, maximum CO_2 and ethylene production occurred during the green stage (Figure 2 and 3 A, D, G, J, and M), coinciding with the findings of Maldonado et al. (2014) for 'Cuernavaqueña', but not with those of Pérez et al. (2004) for 'Amarilla', where peak levels of both gases were observed during the ripe stage. Also, the typical climacteric pattern was absent (Figures 2 and 3), this time coinciding with the findings of Pérez et al. (2004) and Mohammed et al. (2019) but not with those of Sampaio et al. (2008), Osuna et al. (2011), Montalvo et al. (2011) and Romero-Hinojosa et al. (2021), or Maldonado et al. (2014), who found significant increases in CO_2 and ethylene (and thus evidence for *climacteric* behavior) during the ripening of both yellow and red varieties.

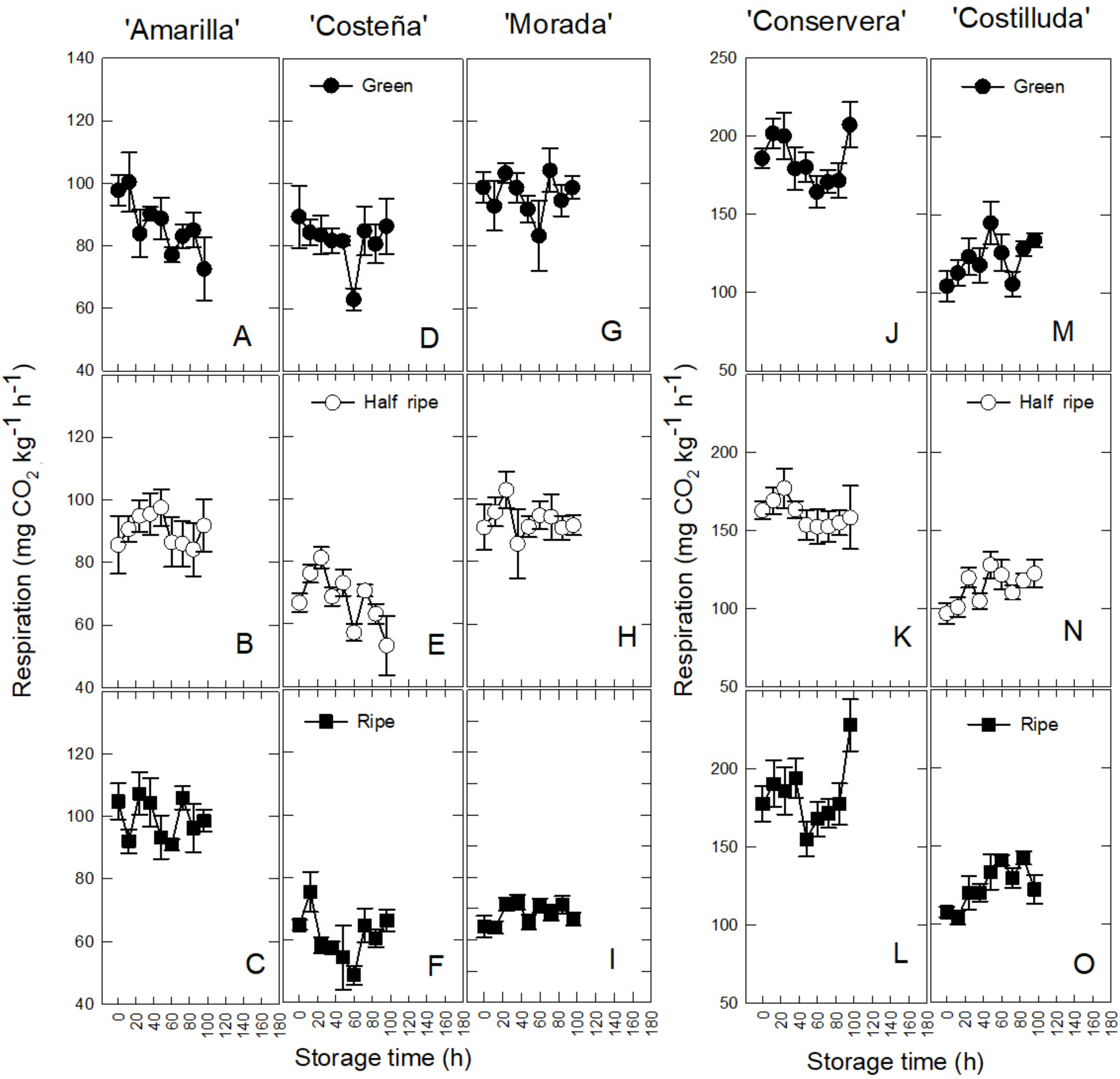

Figure 2 - Rates of respiration in the green-, half ripe-, and ripe-harvested fruit of *S. purpurea* L. evaluated. All five ecotypes were stored at 25 ± 2 °C and 60 % RH. Each point represents the mean of five measurements ± SE.

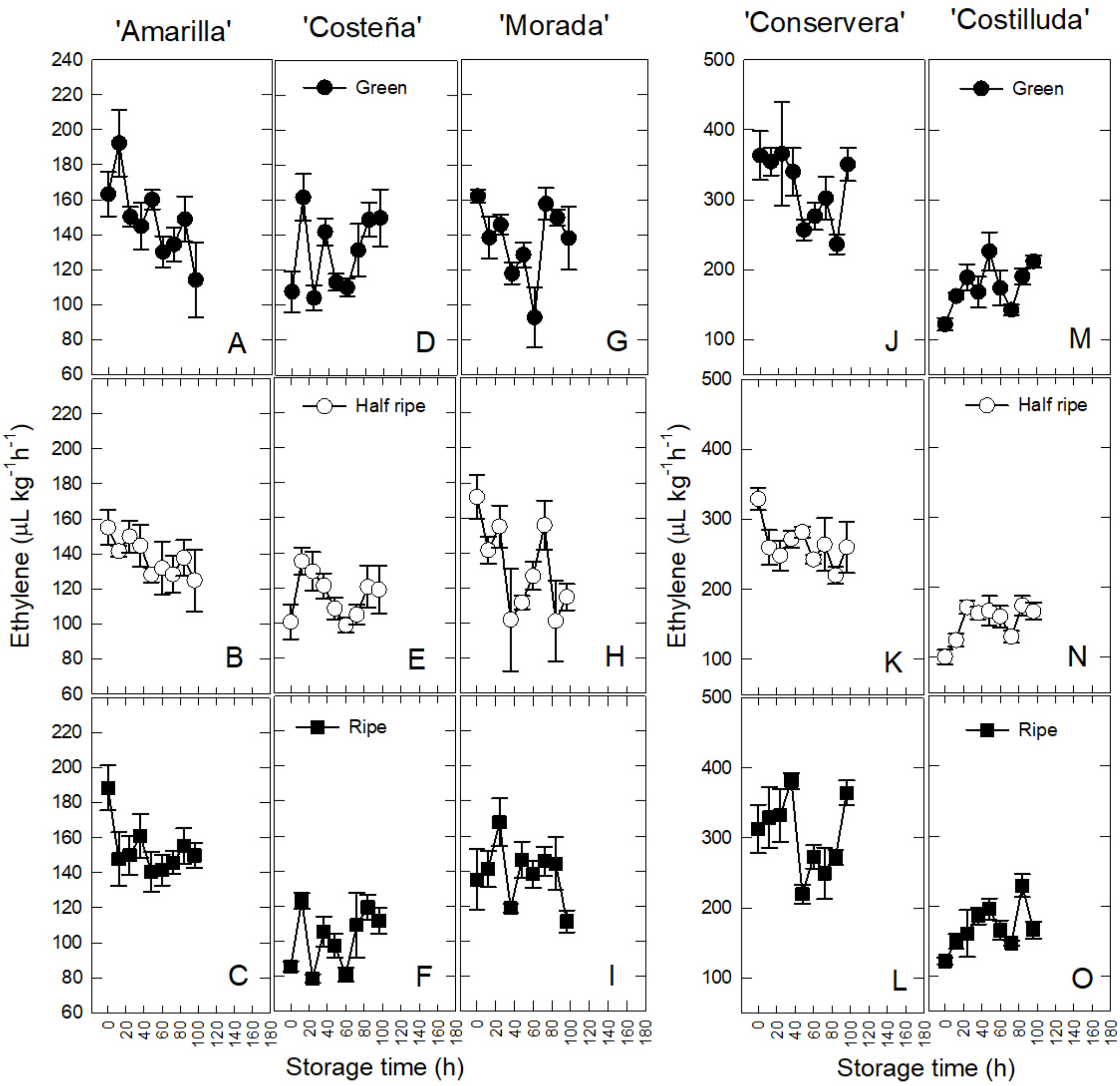

Figure 3 - Ethylene production in the green-, half ripe-, and ripe-harvested fruit of *S. purpurea* L. evaluated. All five ecotypes were stored at 25 ± 2 °C and 60 % RH. Each point represents the mean of five measurements ± SE.

Chromatic parameters Hue angle (h)

Both green- and half ripe-harvested fruit in 'Morada', 'Costeña', and 'Conservera' experienced a color shift from either yellow-green (h = 90–100) or reddish (h = 65-80) to purple-red (h = 25–40) after 4 d at 25 °C, while fully-ripe 'Morada' changed from reddish (h = 40) to purple (h= 25) (Figure 4 A, G, and M). Ripe-harvested 'Costeña' and 'Conservera', on the other hand, remained more or less stable (h=20–25, purple) (Figure 4 G and M). Similarly, the green and half ripe fruit of 'Amarilla' and 'Costilluda' changed from a light green (h ≈ 100) to a light orange (h = 75) while varying little, if any, in their ripe-harvested counterparts (Figure 4 D and J). Sampaio et al. (2008) links chlorophyll degradation as well as carotenoid and anthocyanin synthesis to the majority of these changes, describing them as follows: 1) a dark green to light green during the pre-climacteric; 2) a light green to orange-yellow during the climacteric rise; 3) a purple-red during the climacteric peak; and 4) no color change during the post-climacteric (data from Brazilian-grown *S. purpurea*, with no cultivar or ecotype specified).

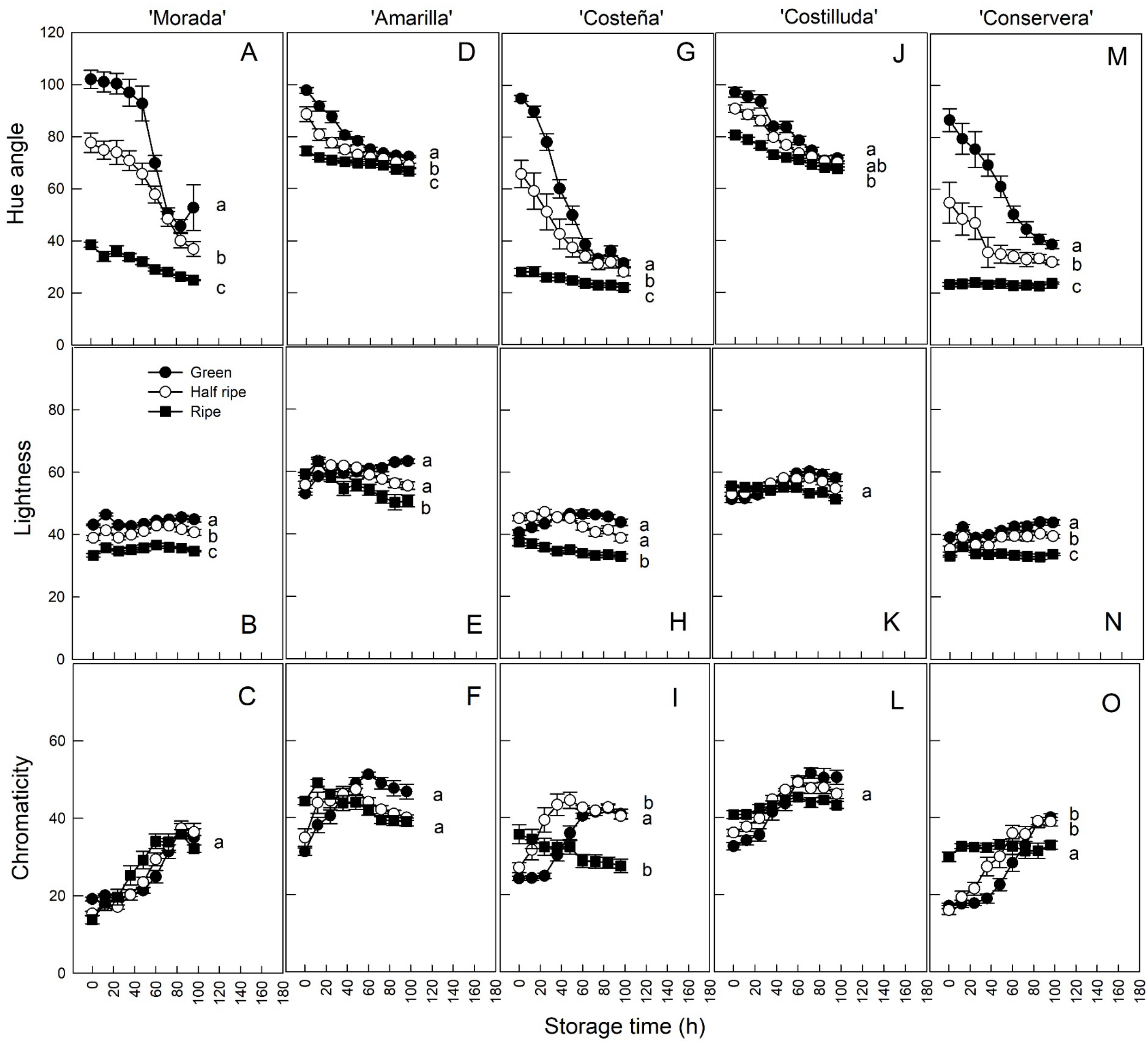

Figure 4 - Color development in the green-, half ripe-, and ripe-harvested fruit of *S. purpurea* L. evaluated. All five ecotypes were stored at 25 ± 2 °C and 60 % RH. Each point represents the mean of five measurements ± SE. Different letters indicate significant differences according to Tukey's HSD (P≤0.05).

Lightness (L*)

This parameter changed little in the green-, half ripe-, and ripe-harvested fruit of all ecotypes – even after 4 d at 25 °C (Figure 4 B, E, H, K, and N). However, initial values were considerably higher in 'Amarilla' and 'Costilluda' (L* = around 60) compared with those in 'Morada', 'Costeña', and 'Conservera' (L* = around 40). This last group, therefore, consists of fruit of a darker (i.e. less luminous) color than the rest.

Chromaticity (C*)

Nearly all green- and half ripe-harvested fruit experienced increments in C* during ripening (Figure 4 C, I, L, and O) as did the already-ripe specimens of 'Morada' (Figure 4C). On the other hand, no change occurred in the ripe-harvested drupes of 'Costilluda' and 'Conservera', with even slight decreases appearing in those of 'Amarilla' and 'Costeña' (Figure 4 F, I, L, and O). Increments in C* generally translate into more saturated colors – a change also reported by other authors irrespective of maturity stage at harvest (e.g. 'Cuernavaqueña' collected during the green, half ripe, and ripe stages); however, this change does appear to be less evident in already-ripe drupes as final coloration is usually reached by this stage (MALDONADO et al., 2014).

Weight loss (WL)

Transpiration (i.e. water loss through the epidermal surface due to a deficit in vapor pressure) is the main cause of WL in horticultural commodities, and this was noticeably higher in 'Costilluda' and 'Conservera' (Figure 5 A–E). For 'Costilluda', this was undoubtedly a result of its epidermal surface, which appeared segmented (characterized by longitudinal subsidence) while for 'Conservera', a greater surface area per unit volume (resulting from its smaller size) was likely the main factor (Figure 1 A and B). In either case, the contact surface available for interaction with the external environment increased, leading to the outcomes obtained.

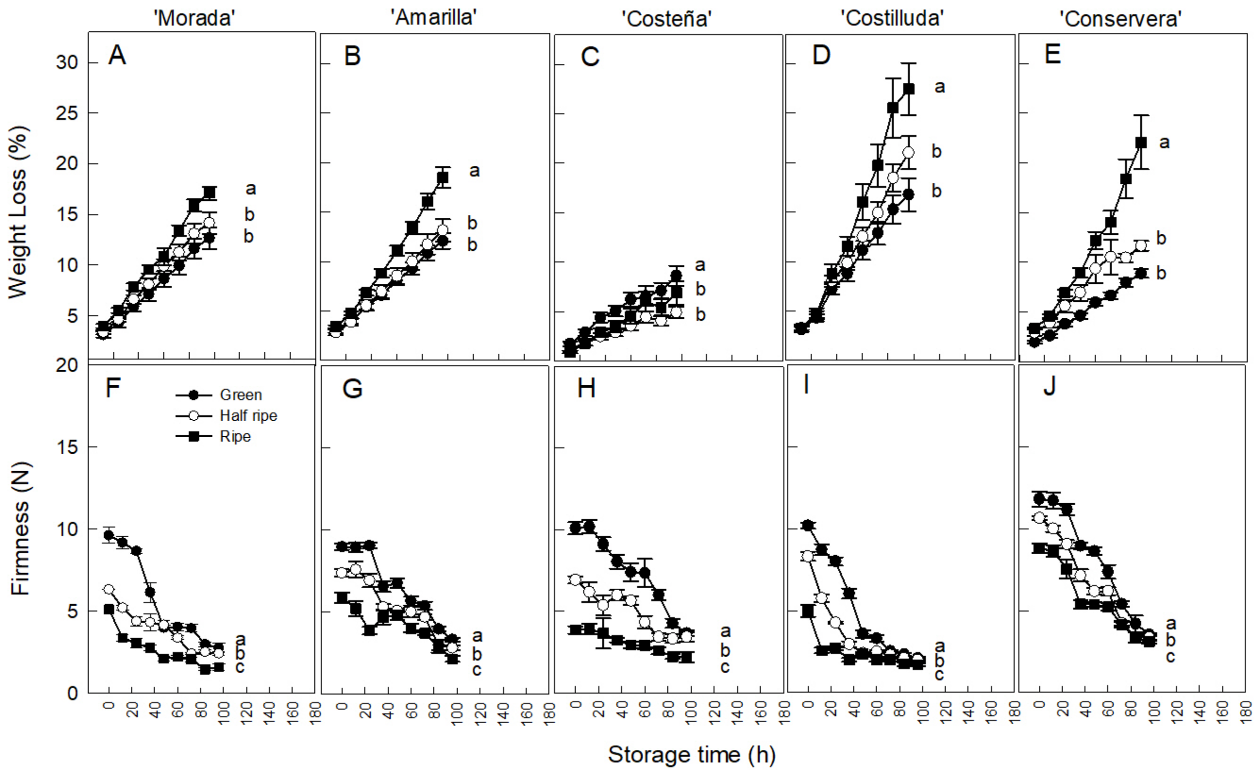

Figure 5 - Weight loss and firmness in the green-, half ripe-, and ripe-harvested fruit of *S. purpurea* L. evaluated. All five ecotypes were stored at 25 ± 2 °C and 60 % RH. Each point represents the mean of five measurements ± SE. Different letters indicate significant differences according to Tukey's HSD (P≤0.05).

WL was also higher in most ripe-harvested fruit, particularly in 'Costilluda', 'Conservera', and 'Amarilla' (27, 22, and 18 % respectively after 4 d at 25 °C) (Figure 5 D, E, and B). In addition, no notable differences were found between those harvested green or half-ripe (except in 'Costeña', where WL was 9 and 5 % in each of these stages respectively) (Figure 5 A–E). Prior studies also report higher WL in ripe-harvested fruit compared to those harvested during earlier stages (i.e. immature, half-ripe, ½ yellow, or ¾ yellow) (SOUSA et al., 1998; PÉREZ et al., 2004), supporting the notion that key changes to the epidermal tissues of *S. purpurea* L. occur during ripening (e.g. ruptures due to the active growth of both rind and pulp during the latter stages of drupe development; thinning or chemical altering of the wax layer, resulting in a less efficient transpiration barrier, etc.). As any WL higher than 10 % begins to impact quality and marketability (e.g. wilting, loss of turgence, etc.), it is strongly recommended that edible coatings be applied to all ecotypes except 'Costeña'.

Firmness

Ripening-related softening in fruits depends on several factors including the species and cultivar in question, as well as the maturity stage at harvest. The reason for this lies in the composition and structure of the cell wall components (PAREEK, 2016), which undergo major changes during this process (e.g. de-polymerization of pectic compounds, chemical and structural changes of hemicellulose, cellulose, etc.). Thus, the expression and activity of various cell wall-modifying enzymes are naturally involved (MALDONADO et al., 2014).

When *S. purpurea* L. is harvested at an immature stage, loss of firmness generally exceeds that of ripe-harvested fruit (sometimes by as much as 30 % or more) (BAUTISTA et al., 2003). Accordingly, the firmness of green-, half ripe-, and ripe-harvested ecotypes decreased from initial values of 9.0–12.0 N, 6.5–9.0 N, and 4.0–9.0 N to final ones of 2.6–4.5 N, 2.5–4.0 N, and 2.0–3.0 N, respectively (i.e. after 4 d at 25 ± 2 °C and 60 % RH) (Figure 5 F–J). In the first two cases, however, (i.e. the green and half ripe stages) firmness was still acceptable from a consumer standpoint. Also, in order to avoid damages due to post-harvest handling, *S. purpurea* L. should not be harvested fully ripe. In this sense, 'Morada' and 'Conservera' would probably fare better when transported long distances (initial average firmness = 8.5 and 11.5 N; final average firmness = 3.0 – 4.0 N), while fruit from 'Amarilla' should definitely be handled more carefully, even when harvested green or half ripe (initial average firmness = 8.0 N; final average firmness = 2.5 N) (Figure 5 F–J).

pH

This variable increased independently of ecotype and maturity stage at harvest (Figure 6 A–E); nevertheless, important trends were still observed.

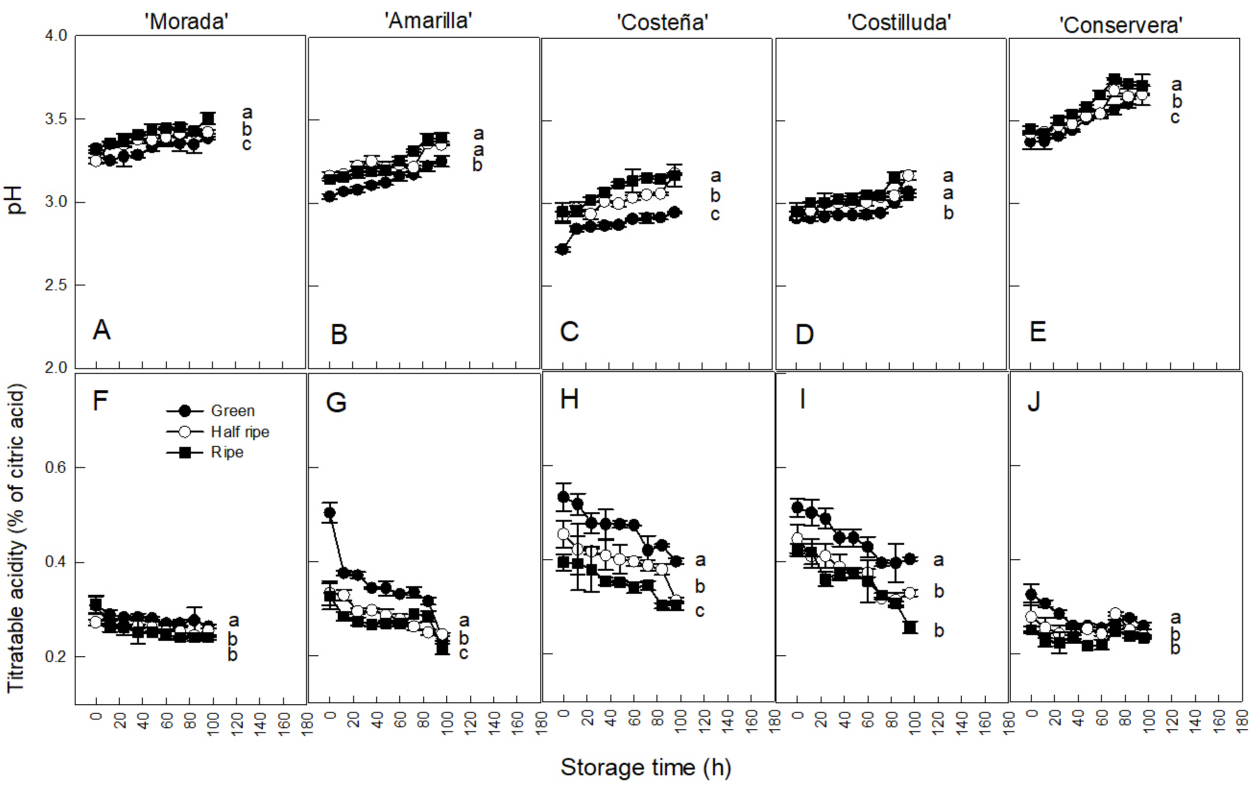

Figure 6 - Titratable acidity and pH in the green-, half ripe-, and ripe-harvested fruit of *S. purpurea* L. evaluated. All five ecotypes were stored at 25 ± 2 °C and 60 % RH. Each point represents the mean of five measurements ± SE. Different letters indicate significant differences according to Tukey's HSD (P≤0.05).

For instance, in 'Amarilla' and 'Costilluda', the pH of half ripe- and ripe-harvested fruit was greater than that obtained from green-harvested specimens, and all three were noticeably different in 'Morada', 'Costeña', and 'Conservera' (Figure 6 A–E). On average, however, pH was greatest in 'Conservera' (3.4 and 3.7 during its green and ripe stages), followed by values in 'Morada' (3.2 and 3.5), 'Amarilla' (3.1 and 3.4), 'Costeña', and 'Costilluda' (2.7 and 3.2 during the green and ripe stages of both, respectively) (Figure 6 A–E). Similar increments in pH are also reported by other authors (e.g. 3.0–3.4 by CUNHA et al., 2001 and 2.6–3.4 by BEZERRA et al., 2011 during the green-to-ripe transition), with higher values generally attained by green-harvested fruit (when compared, for instance, to ripe-harvested ones) (DÍAZ et al., 1999; BAUTISTA et al., 2003).

Titratable acidity (TA)

Most fruits are rich in organic acids, which can either be found free or in the form of salts, esters, and glycosides inside the vacuoles of plant cells. Thus, a common method used to determine their content is to measure the TA of liquified samples (usually juice). However, this only takes into account the organic acids in free form, along with phosphoric acid and certain phenols (ULRICH, 1970). For this reason, TA is often reported in terms of the most abundant organic acid in the particular fruit under study. For most species, organic acids decrease during ripening as they are either used for respiration (i.e. as respiratory substrates) or are otherwise transformed into sugars (WILLS and GOLDING, 2016).

As expected, TA decreased during the ripening of all ecotypes evaluated (Figure 6 F–J), coinciding with the previously discussed increments in pH (see prior section above). In addition, maturity stage at harvest also influenced these values (Figure 6 F–J). Specifically, in 'Morada' and 'Conservera', TA decreased from 0.32–0.28 % after 4 d of ripening (Figure 6 F and J), while in 'Costeña' and 'Costilluda', values changed from an initial range of 0.40–0.55 % to a final one of 0.3–0.5 % (Figure 6 H and I). Similarly, in 'Amarilla', values decreased from 0.3–0.5 % at the beginning of the study, to just 0.2 % by d 4 (Figure 6 G).

Changes in the TA of *S. purpurea* L. occur regardless of either maturity stage (1.17–0.19 % according to BAUTISTA et al., 2003; SAMPAIO et al., 2008; BEZERRA et al., 2011; ROMERO-HINOJOSA et al., 2021) or ecotype/geographic origin (0.2–12.28 % in different accessions from the Mexican states of Morelos, Guerrero and Chiapas, according to (ALIA et al., 2012; VILLARREAL-FUENTES et al., 2019). For instance, in 'Cuernavaqueña' the TA of green-, half ripe-, and ripe-harvested fruit is reported to decrease from 0.68–0.5 %, 0.59–0.43 %, and 0.51–0.43 %, respectively (MALDONADO et al., 2014). However, values in our study are substantially lower than those mentioned previously. This is important because TA, when properly balanced with the content of sugars, significantly contributes to the perception of taste in fruit [i.e. the sweetness-acidity balance]) (WILLS; GOLDING, 2016). TA is also important for processing because the quantity of certain additives – as well as the specific conditions applied – strongly depend on it, with more acidic products generally preferred. For this reason, fruit from the five ecotypes studied would probably be better suited for fresh consumption.

Total soluble solids (TSS)

This is a measure of the combined sugars, organic acids, water-soluble vitamins, inorganic salts, and free amino acids in fruit. However, as sugars always predominate, TSS has instead become a practical indicator of their content – one that is closely tied to sweetness. Increments in TSS during maturation are mostly due to the hydrolysis of polysaccharides (usually starch), though postharvest water loss, glucoside breakdown, and the synthesis of soluble pigments (e.g. anthocyanins) also play a role (PÉREZ et al., 2004; PEREIRA et al., 2003). Additionally, immature fruit of *S. purpurea* contain considerable amounts of mesocarp starch (approximately 9.0 g 100 g^{-1}) – 80 % of which is hydrolyzed during ripening – leading to an increase in glucose and fructose (CUNHA et al., 2001).

In this study, ripening-related increments in TSS differed according to maturity stage at harvest (Figure 7 A–E). Initial and final values (i.e. after 4 d at 25 °C) ranged from 3–10 % and 9–12 % respectively, except in 'Conservera', were final TSS was much higher (14–17 %), suggesting larger quantities of starch. Similar intervals are also reported by other authors independently of ecotype (e.g. final TSS = 17–18 % after 5 d at 25 °C in 'Cuernavaqueña', according to MALDONADO et al., 2014; 9–18 % in 11 ecotypes of *S. purpurea* L. at the ripe stage, according to SOLORZANO et al., 2015 and 3.1-24.3 % in 80 different trees of Mexico, according to ALVAREZ-VARGAS et al., 2022). As values between 8 and 16 % are what is usually recommended for commercial purposes (RAMÍREZ et al., 2008), all five ecotypes would also likely be suited for large-scale cultivation.

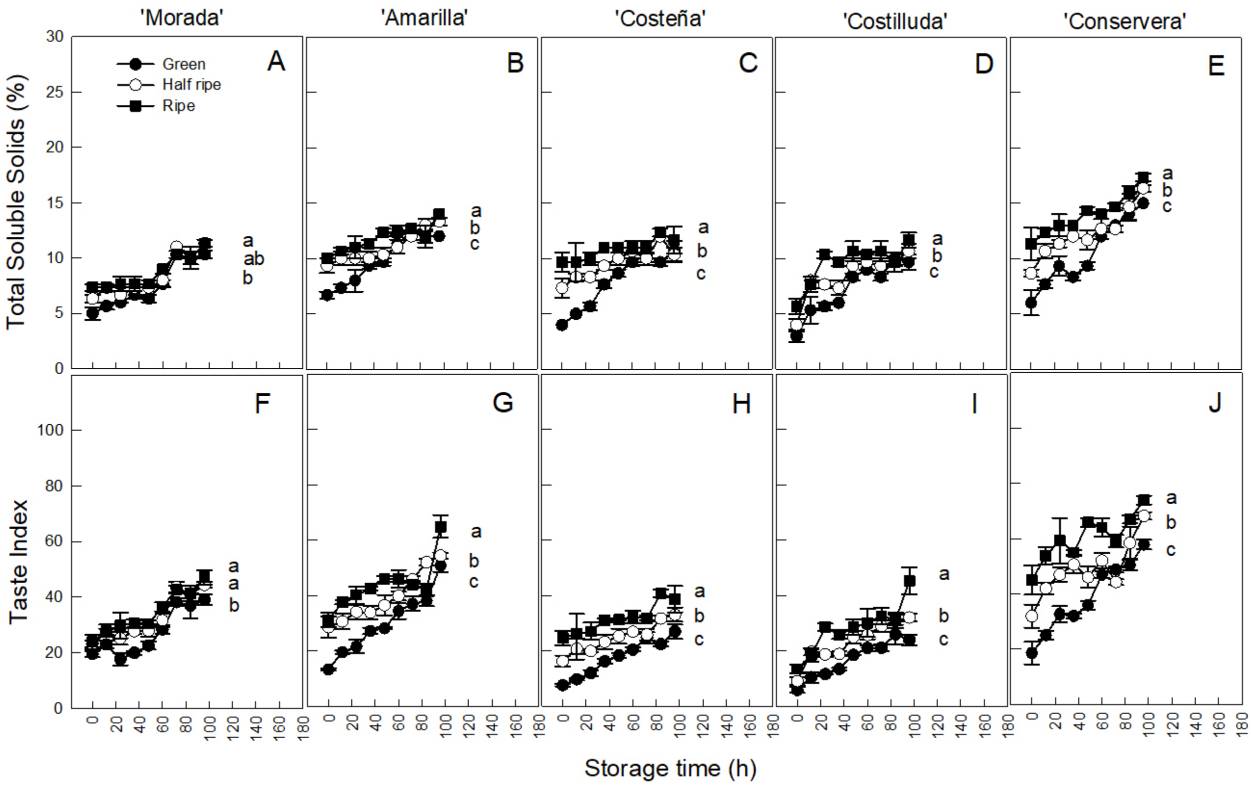

Figure 7 - Taste index and total soluble solids in the green-, half ripe-, and ripe-harvested fruit of *S. purpurea* L. evaluated. All five ecotypes were stored at 25 ± 2 °C and 60 % RH. Each point represents the mean of five measurements ± SE. Different letters indicate significant differences according to Tukey's HSD (P≤0.05).

Taste index (TI)

The TSS/TA ratio is, on the other hand, related to the sensory perception of both sweetness and acidity in fruit, and can thus be regarded as a form of taste index (TI) (LADANIYA et al., 2008). In this study, the TI increased with maturity stage at harvest except in 'Morada', where no differences were detected between the half ripe and ripe stages (Figure 7 F–J). Such increments can best be explained by the simultaneous rise in TSS and decrease in acidity that normally accompany fruit ripening.

Prior studies report TI intervals of 3–63 and 38–40 in the ripe-harvested and mixed (i.e. green, half ripe, and ripe) fruits of *S. purpurea* L., respectively (ALIA et al., 2012; MALDONADO et al., 2014). In this work, however, values of 2.9–75 were calculated instead – with a considerable higher interval of 39–75 obtained by just considering data from 'Amarilla', 'Morada', and 'Conservera'. Thus, TI values in these ecotypes appear to be the highest out of any *S. purpurea* L. fruit from Mexico.

The high perishability that characterizes this species, the scarce or non-existent reports of suitable preservation technologies, and the incipient knowledge of the physiological changes that occur after harvest, are among the main reasons these fruits remain poorly commercialized to this day. It is our hope that with the data provided, the *S. purpurea* L. ecotypes with the greatest commercial potential will be selected for large-scale cultivation and development by both current and future generations of growers.

Conclusions

The five ecotypes of *S. purpurea* L. fruit experienced physical, chemical, and physiological changes consistent with a climacteric pattern of respiration, though no such process was actually observed. In addition, maturity stage at harvest affected the values of most measured variables, with the half ripe stage associated with higher fruit yields and quality; nevertheless, the ecotypes with the best overall quality were 'Amarilla' and 'Costeña'. Lower rates of respiration and of ethylene production correlated well with longer postharvest lives, which were again, greatest among the latter two ('Amarilla' and 'Costeña'). 'Conservera', on the other hand, possessed the highest TSS and TI values, while 'Amarilla' was the most likely sensitive to postharvest handling (with 'Morada' and 'Conservera' being the least). The effect of postharvest practices and technologies should, however, continue to be evaluated in all five ecotypes as the latter remains crucial for further increasing the quality and shelf life of *S. purpurea* L.

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