Fruits, 2015, vol. 70(5), p. 261-270

DOI: 10.1051/fruits/2015027

FRUITS

Available online at:
www.fruits-journal.org

ORIGINAL ARTICLE

Quality attributes and functional compounds of Mexican plum (*Spondias purpurea* L.) fruit ecotypes

Susana Solorzano-Morán[1], Irán Alia-Tejacal[1,*], Fernando Rivera-Cabrera[2], Víctor López-Martínez[1], Laura Josefina Pérez-Flores[2], Clara Pelayo-Zaldívar[2], Dagoberto Guillén-Sánchez[1], Fernando Díaz de León-Sánchez[2] and Yanik Ixchel Maldonado-Astudillo[3]

[1] Posgrado en Ciencias Agropecuarias y Desarrollo Rural, Facultad de Ciencias Agropecuarias, Universidad Autónoma del Estado de Morelos. Av. Universidad 1001, Chamilpa, 62209, Cuernavaca, Morelos, México
[2] Universidad Autónoma Metropolitana. Av. San Rafael Atlixco 186, Col. Vicentina. 09340, Iztapalapa, Distrito Federal, México
[3] Unidad Académica de Ciencias Químico Biológicas. Universidad Autónoma de Guerrero. Av. Lázaro Cárdenas s/n. Ciudad Universitaria sur, col. La haciendita, 39090. Chilpancingo de Los Bravo, Guerrero, México

Received 30 September 2014 – Accepted 23 April 2015

Abstract – Introduction. Mexico harbors a great diversity of *Spondias purpurea* ecotypes, whose fruit is called Mexican plum and has a good consumer acceptance because of its organoleptic and nutritional characteristics. **Materials and methods.** The concentrations of metabolites in 11 ecotypes of Mexican plum were determined from samples of rind (epicarp) and pulp originating from fresh seasonal fruit. **Results and discussion.** The mass of these fruits varied from 11.1 to 35.0 g, and the epicarp color ranged from purple and red, to orange and yellow. The content of total soluble solids, total sugars, and vitamin C was of 9.4−18.2 °Brix, 101.0−185.9 mg g^{-1} fresh weight (FW), and 0.6−2.1 mg g^{-1} FW, respectively. The total phenolic content was always higher in the epicarp (3.7 mg g^{-1} FW) than in the pulp (1.3 mg $^{-1}$ FW), as was the total content of carotenoids and the levels of antioxidant activity. Additionally, positive correlations could be established between antioxidant activity and total phenolics, total phenolics and total carotenoids, and between the antioxidant activity in the epicarp and the total content of vitamin C. In addition, negative correlations were found between hue and the carotenoid content of the pulp, and between hue and the antioxidant activity in the epicarp and pulp. **Conclusion.** The results suggest that a higher content of phenols, carotenoids, and vitamin C, together with a purple or red coloration of the epicarp, can all be associated with an increase in the antioxidant activities of the epicarp and pulp of the Mexican plum.

Keywords: Mexico / Latin America / Mexican plum / *Spondias purpure*a / antioxidant activity / carotenoids / phenolics / vitamin C / nutritional value

Résumé – Attributs de qualité et composés fonctionnels des fruits de divers écotypes de prune mexicaine *(Spondias purpurea* L.). Introduction. Le Mexique abrite une grande diversité d'écotypes de *Spondias purpure*a dont le fruit est appelé prune mexicaine et possède une bonne image auprès des consommateurs en raison de ses caractéristiques organoleptiques et nutritionnelles. **Matériel et méthodes.** Les concentrations en métabolites de 11 écotypes de prune mexicaine ont été déterminées à partir d'échantillons de la peau (épicarpe) et de la pulpe de fruits frais de saison. **Résultats et discussion.** La masse de ces fruits s'est inscrite entre 11,1 et 35,0 g, et la couleur de l'épicarpe pouvait varier du rouge violacé à l'orange et au jaune. Le contenu en solides solubles totaux, en sucres totaux, et en vitamine C variait de 9,4 à 18,2 °Brix, de 101,0 à 185,9 mg g^{-1} poids frais (FW), et de 0,6 à 2,1 mg g^{-1} FW, respectivement. Le contenu phénolique était toujours plus élevé dans l'épicarpe (3,7 mg g^{-1} FW) que dans la pulpe (1,3 mg g^{-1} FW), tout comme la teneur en caroténoïdes totaux et les niveaux d'activité anti-oxydante. En outre, des corrélations positives ont pu être établies entre l'activité anti-oxydante et les composés phénoliques totaux, entre les composés phénoliques totaux et les caroténoïdes totaux, et entre l'activité anti-oxydante dans l'épicarpe et la teneur totale en vitamine C. En outre, des corrélations négatives ont été trouvées entre la teinte et la teneur en caroténoïdes de la pulpe, et entre la teinte et l'activité anti-oxydante de l'épicarpe et de la pulpe. **Conclusion**. Les résultats suggèrent qu'une plus forte teneur en phénols, caroténoïdes, vitamine C et une coloration rouge pourpre de l'épicarpe peuvent toutes être associées à une augmentation des activités anti-oxydantes de l'épicarpe et de la pulpe de la prune mexicaine.

Mots clés : Mexique / Amérique latine / prune mexicaine / *Spondias purpurea* / activité anti-oxidante / carotenoïdes / composés phénoliques / vitamine C / valeur nutritionnelle

* Corresponding author: iran.alia@uaem.mx

1 Introduction

Mexican plum fruit (*Spondias purpurea* L.) originates from southern Mexico and Central America, although its present range also extends into South America to include Peru and Brazil, where it can be found growing wild or cultivated [1]. In Mexico its distribution spans much of the country's Pacific slope, from the coast of Sonora in the Gulf of California, to Chiapas and the Balsas Basin in the south. Additionally, its range also includes the Chiapas Depression as well as the northern portions of the states of Yucatan and Quintana Roo (both delimiting the Gulf of Mexico), and to the east, northern Veracruz and the eastern half of San Luis Potosi, in regions populated by lowland deciduous forests [2].

In Mexico, nearly 30 ecotypes have been reported [3] differing primarily on the specific timing of fruit production, which may occur either during the rainy or the dry season [4]. Additionally, Mexican plum is considered a crop with a high potential for cultivation due to its relatively low cost of production as well as its general resistance to drought, a characteristic that has been attributed to its specific mechanism of defoliation and which gives the plant the ability to spontaneously grow in, and adapt to, poor and thin soils, conditions that would otherwise be unsuitable for the establishment of other crops [3, 5]. In fact, Ramirez *et al*. [6] suggest its use as a strategic species for agriculture in regions of Mexico where no other fruit production occurs during periods of drought and which may, as a result, enable the fruit to reach a relatively high price on the market.

Mexican plum fruit is round, oblong, or ovoid drupes of various weights and sizes typically ranging between 4−33 g and 2−5 cm respectively, with smooth to semi-smooth, thin epicarp that may turn red, yellow, reddish-brown, orange or purple when ripe. Additionally, their endocarp is thick and fibrous and their mesocarp has a pleasant flavor and aroma [3,5]. Notably, the ecotypes that produce fruit during the dry season have an epicarp with a red, orange, yellow, purple, or maroon color at consumer maturity (the ripe stage) [7, 8], while those that produce fruit during the rainy season are characterized by having yellow or orange fruit [9].

Mexican plum fruit can be consumed at both ripe and unripe stages [6]. Ripe fruits however, supply a high intake of calories in addition to vitamin C and moderate amounts of minerals such as potassium and calcium [10] together with antioxidant compounds such as phenols and carotenoids [11]. Mexican plum is also a fruit with a high potential for commercialization (indicated by its wide demand in regional markets) because of its excellent sensory characteristics coupled with the aforementioned nutritional properties [5, 10].

During the past decade, much research was devoted to try and establish the precise relationship between reactive oxygen species (ROS) and the development of various diseases such as cancer, arthritis and different kinds of cardiovascular problems, as well as the degenerative processes associated with aging, including Alzheimer and Parkinson diseases [12]. Recently, several epidemiological studies suggest that the consumption of fresh fruit, vegetables or different types of herbal infusion has protective effects against such diseases with the beneficial outcomes being attributed in part to the presence of a wide variety of nutrients such as vitamins, flavonoids, carotenoids, anthocyanins and phenolic compounds among others [13, 14]. These antioxidant compounds have the ability to eliminate or suppress the deleterious effects of ROS thereby reducing the level of cellular oxidative stress and preventing damage from occurring to important biocompounds [15].

Table I. Sampling location and epicarp color of the 11 evaluated ecotypes of Mexican plum fruit (*Spondias purpurea*).

Ecotype	Sampling location in Mexico	Epicarp color
'Gorda'	Teloloapan, Guerrero	Orange
'Costeña'	Acapulco, Guerrero	Red
'Jocote'	Chiapa de Corzo, Chiapas	Yellow
'Conservera'	Tepecoacuilco, Guerrero	Purple
'Costilluda'	Axochiapan, Morelos	Yellow
'Bolsuda'	Tepecoacuilco, Guerrero	Red
'Amarilla'	Huitzuco, Guerrero	Yellow
'Chapilla'	Chiapa de Corzo, Chiapas	Orange-red
'Morada'	Cocula, Guerrero	Red
'Venado'	Zumpango, Guerrero	Orange
'Conservera de Tlaxmalac'	Huitzuco, Guerrero	Red-purple

In addition to their biological properties, natural antioxidants are also of particular interest to the fields of cosmetology, pharmacology and especially, to the food industry [16] due to the protection they provide against the oxidative degradation of commercial products. Moreover, it is recognized that fruits are an important source of antioxidant compounds and that these contribute to their chemopreventive potential [17, 18].

At present, there are no scientific reports evaluating the content of functional compounds with antioxidant capacity present in the pulp and rind of the various ecotypes of Mexican plum. The aim of this study was therefore to quantify the content of phenols, carotenoids, and vitamin C, together with the total antioxidant capacity in the rind and pulp of the Mexican plum fruit harvested for fresh consumption.

2 Materials and methods

2.1 Plant material

Between 50 and 60 fruits, representing 11 different ecotypes of Mexican plum, were collected from the Mexican states of Morelos, Guerrero, and Chiapas at a stage of development that corresponded to 'consumer maturity', where the fruits were deemed ripe enough to give an acceptable or palatable product. Some characteristics of these ecotypes are presented in *table I* [19].

2.2 Sample preparation

The fruits were transferred to the Agricultural Production Laboratory in the Faculty of Agricultural Sciences at the Autonomous University of the State of Morelos, Mexico and allowed to stand until the fruits were at room temperature (23 ± 2 °C, 50−60% relative humidity). Subsequently, they were washed with a solution of sodium hypochlorite 1% (w/v), rinsed with distilled water, and screened for the absence of mechanical damage or decay. These procedures were all performed on the same day that harvesting took place. Determinations of mass, color, total soluble solids (TSS), and titratable acidity (TA) were all performed on fresh fruit; for other analyses, frozen fruits stored at −20 °C were used.

2.3 Mass, color and total soluble solids (TSS)

Individual measurements of mass and color were made on 10 different fruits with the use of a digital balance (OHAUS®, USA, 0.01 g sensitivity) and a spectrophotometer (X-rite® mod. 3290, USA), respectively. For color, values of lightness (L*), chroma (C*), and hue (h) were obtained from the fruit epicarp at two opposing regions located in the equatorial section of each fruit [20]. For each of the fruits evaluated, the juice from a piece of peel-pulp was obtained with an Atago extractor (RE-29401) and the TSS measured from a juice drop using a hand-refractometer (Atago PAL-1®, Japan); the results are reported in °Brix.

2.4 Sugar extraction and quantification

Total sugars were determined using the anthrone method [21]. Accordingly, the fruit pulp from each of the 10 frozen fruits was separated, cut into small pieces, and 1 g placed (in triplicate) inside glass jars, into which 50 mL of 80% ethanol (v/v) were added. The samples were then boiled for 3−5 min and the resulting extract stored under refrigeration at 5 °C. After 15 days, 1 mL of each supernatant was placed inside 10 mL beakers and allowed to evaporate at a temperature $\leqslant$ 50 °C, with the subsequent residue later dissolved in 50 mL distilled water. Next, 1 mL of this solution was placed inside tubes with flat bottoms and adjusted to 3 mL with distilled water. To each of these tubes, 6 mL of a 0.4% solution of anthrone were added (0.4 g anthrone in 100 mL of sulfuric acid at 98.8%), all the while maintaining the tubes inside an ice bath. Subsequently, the tubes were immersed in a water bath for 3 min and cooled again inside an ice bath before absorbances were finally read at 600 nm with the aid of a spectrophotometer (Genesys 6®, Milton Roy), using a mixture of 3 mL distilled water and 6 mL of 0.4% anthrone as a blank. In order to calculate the total concentration of sugars, a glucose calibration curve was subsequently used.

2.5 Total phenolic content

For the quantification of total phenols, the Folin-Ciocalteu method was used [22]. Consequently, a 1 g sample of either the rind or the pulp of a Mexican plum fruit was macerated inside a 30 mL plastic tube into which 15 mL of a cold 80% methanol solution (v/v) were added. The mixture was homogenized and centrifuged for 5 min (4,000 *g*) and the supernatant used to determine the total phenolic content. The reaction mixture contained 0.2 mL of the supernatant diluted with 17 mL distilled water (1:85) and 1 mL Folin-Ciocalteu reagent. The mixture was stirred by hand and afterwards, 2 mL of a saturated sodium carbonate solution were added. It was then stirred again and incubated for 90 min. The total phenolic content of the sample was quantified by measuring the absorbance at 760 nm using a spectrophotometer (Genesys 6®, Milton Roy). In order to determine the concentration of total phenols, a standard curve was prepared using tannic acid. Results were reported in mg g^{-1} fresh weight (FW).

2.6 Total carotenoid content

For the extraction and quantification of total carotenoids the methodology described by Alia *et al.* [23] was used. A total of 15 mL acetone was therefore added to 1 g fruit tissue (either pulp or rind) and the mixture macerated in a cold mortar. The resulting homogenate was placed inside a 500 mL separating funnel into which either 30 mL or 20 mL hexane were added depending on whether the sample consisted of fruit rind or pulp tissue respectively. Lastly, 100 mL distilled water were added to either of the two mixtures which were subsequently stirred and allowed to stand until complete separation occurred between the top and aqueous phases, which contained either the carotenoids (dissolved in hexane solvent) or the acetone, respectively. The latter phase was discarded, and the carotenoid-containing extract was washed 4 to 5 times with 100 mL distilled water in order to remove any traces of acetone. Finally, after the extract was passed through a filter paper containing a layer of anhydrous sodium sulfate, the final volume of the filtrate was determined, and part of that volume used to read the absorbance of the solutions at 452 nm with the use of a spectrophotometer (Genesys 6®, Milton Roy). Because sample absorbances are reported to range between 0.2 to 0.8 [24], dilutions of 1:1, 1:2, or 1:3 were made using hexane whenever readings were above this range until the desired (target) range was achieved. The absorbance values obtained were then used to calculate the total carotenoid content, as β carotene [38] using the following equation:

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

where: A = absorbance, volume = total volume of extract, and $A_{1\ cm}^{1\%} = 2,580$ β-carotene in hexane. The results were expressed as mg total carotenoids 100 g^{-1} fresh weight (FW).

2.7 Vitamin C content

Vitamin C is usually quantified in the pulp (*e.g.* banana, citrus, pineapple) or in the whole fruit (strawberry, blueberry), but not in the peel separated from the pulp. In the case of *Spondias purpurea* fruit, some consumers use to eat peel and pulp together and for this reason in the present study, assays were conducted in fruit samples consisted of both epicarp and pulp. The vitamin was determined according to the method proposed by Jagota and Dani [25], which relies on a spectrophotometric technique that is based on the Folin-Ciocalteu reaction.

Table II. Quality attributes of the11 evaluated ecotypes of Mexican plum fruit (*Spondias purpurea*). Mass (g); L*: lightness (0-white; 100-black); C*: chroma (vivid-opaque); h: hue angle (0-red; 90-yellow); TSS: total soluble solids (°Brix); TS: total sugars (mg g^1 FW); HSD: honest significant difference; VC: variation coefficient.

Ecotype	Mass	L*	C*	h	TSS	TS
'Gorda'	12.3^{c}	37.5^{d}	44.4^{c}	29.6^{cd}	17.8^{ab}	$138.1^{b–d}$
'Costeña'	20.4^{b}	34.9^{de}	36.5^{d}	25.6^{d}	14.1^{ab}	111.1^{d}
'Jocote'	34.8^{a}	54.0^{b}	51.5^{b}	71.7^{a}	13.9^{b}	120.9^{cd}
'Conservera'	15.7^{c}	28.8^{f}	28.7^{e}	18.3^{e}	14.5^{ab}	127.3^{cd}
'Costilluda'	11.1^{c}	59.3^{a}	62.0^{a}	70.0^{a}	14.5^{ab}	136.2^{cd}
'Bolsuda'	13.3^{c}	37.2^{d}	40.3^{cd}	32.1^{c}	9.4^{c}	101.6^{d}
'Amarilla'	11.1^{c}	52.1^{b}	41.9^{cd}	72.9^{a}	13.8^{b}	121.2^{cd}
'Chapilla'	13.9^{c}	45.0^{c}	43.4^{c}	64.2^{b}	16.1^{ab}	177.9^{ab}
'Morada'	14.6^{c}	34.7^{de}	43.5^{c}	30.5^{cd}	14.5^{ab}	$157.9^{a–c}$
'Venado'	12.4^{c}	34.8^{de}	43.0^{c}	30.3^{cd}	14.4^{ab}	$141.2^{b–d}$
'Conservera de Tlaxmalac'	12.5^{c}	31.4^{ef}	39.7^{cd}	26.3^{d}	18.2^{a}	185.9^{a}
HSD	*4.6*	*3.8*	*5.6*	*5.5*	*4.1*	*41.3*
VC (%)	*13.7*	*18.4*	*6.4*	*8.9*	*8.6*	*10.2*

Same letters in each column indicate statistical similarity according to the Tukey's test.

First, 0.8 mL of a 10% (w/v) trichloroacetic acid (TCA) solution were added to a 0.2 mL sample of fruit homogenate inside a test tube (1 g fruit pulp with the epicarp still attached, homogenized using 10 mL distilled water). The mixture was placed in an ice bath for 5 min and centrifuged at 4,000 *g* for another 5 min. For the reaction, 0.5 mL aliquots of the resulting supernatant were diluted with 2 mL of doubly distilled water, and to these, 200 µL of a 1:10 dilution of Folin-Ciocalteu reagent were then added and allowed to stand for 10 min, with absorbances measured at 760 nm. In order to calculate the vitamin C content of the samples, a standard curve was constructed using ascorbic acid, with total vitamin C concentrations expressed as mg g^{-1} FW.

2.8 Antioxidant activity

The evaluation of the antioxidant capacity was performed using the DPPH method reported by Brand-Williams *et al.* [26] which quantifies the ability of the fruit extract to trap free radicals using the synthetic radical 2,2-diphenyl-1-picrylhydrazyl (DPPH). The basis for this method relies on the resulting decrease in absorbance values of DPPH, measured at 515 nm, occurring as a result of the presence of antioxidant compounds in the sample. Antioxidant compounds were extracted from 1.0 g of either fruit pulp or epicarp in 10 mL of 80% (v/v) aqueous methanol containing 2 mM sodium fluoride. The homogenate was centrifuged at 5000 *g* for 10 min using a Beckman GS-15R centrifuge (Beckman Coulter, Inc.). The reaction mixture contained 50 µL of the fruit extract or of the appropriate dilution and 950 µL of DPPH 0.6 mM in methanol and the absorbance was measured after 15 min using a spectrophotometer (Genesys 6®, Milton Roy). The standard curve was prepared with ascorbic acid concentrations ranging from 0 to 600 µM. The results were expressed as units of "antioxidant capacity equivalent to concentration of ascorbic acid" (ACECA) g^{-1} FW.

2.9 Statistical analysis

All evaluations of the phenol, carotenoid, and vitamin C concentrations, as well as the determinations of antioxidant capacity, were performed in triplicate for each of the Mexican plum ecotypes examined. In all cases, an analysis of variance and a comparison of means by Tukey's method, with a probability of 5%, were performed. Subsequently, a multivariate analysis of grouping and sorting was applied to the data using the Numerical Taxonomy software NTSYSpc 2.1. For groupings, the sequential, hierarchical, agglomerative, and nest (SHAN) method was used. With this method, a clustering dendrogram was constructed using the obtained ligament averages (UPGMA). Then, principal component analysis (PCA) was used for ordination analyses, with a standardized correlation matrix between characters. With these analyses, the characters that contributed the most to differentiate the 11 evaluated ecotypes of Mexican plum fruit were identified.

3 Results and discussion

3.1 Fruit quality in the Mexican plum ecotypes examined

Of all the analyzed fruits, 80% had a mass that ranged between 11.1 and 15.7 g, with the remaining 20% falling between 20.0 and 35.0 g (*table II*). The ecotype 'Jocote', collected from the Mexican state of Chiapas, had the biggest mass on average, while the ecotype s'Amarilla' and 'Costilluda', from the states of Guerrero and Morelos respectively, had the lowest (*table II*). Nava and Uscanga [27], for their part, recorded mass values that ranged between 8.7 g ('Roja Ácida') and 37.0 g ('Cabeza de Loro') when analyzing 12 ecotypes of Mexican plum from the state of Veracruz, Mexico. In the mean time, Alia-Tejacal *et al.* [19] determined that 'Jocote' had the greatest mass (43.2 g) when examining 67 fruit samples collected

Table III. Concentration of total phenolics and total carotenoids in the 11 evaluated ecotypes of Mexican plum fruit (*Spondias purpurea*). Phenols in epicarp and pulp (mg g^{-1} FW); Carotenoids in epicarp and pulp (mg 100 g^{-1} FW); Vitamin C in fruit (mg ascorbic acid g^{-1} FW); AA: antioxidant activity (mM ascorbic acid g^{-1} FW). HSD: honest significant difference; VC: variation coefficient.

Ecotypes	Phenols in epicarp	Phenols in pulp	Carotenoids in epicarp	Carotenoids in pulp	Vitamin C	AA in epicarp	AA in pulp
'Gorda'	3.7^{a-d}	1.0^{cd}	7.5^{de}	0.9^{de}	2.1^{a}	4.8^{a}	0.5^{c-d}
'Costeña'	2.7^{cd}	0.9^{cd}	18.6^{b-e}	0.6^{e}	1.3^{a-c}	4.0^{ab}	0.5^{c-d}
'Jocote'	2.2^{cd}	1.0^{cd}	7.6^{de}	1.6^{c-e}	0.6^{c}	3.3^{b}	0.8^{bc}
'Conservera'	5.1^{ab}	0.9^{cd}	8.7^{de}	0.6^{e}	0.8^{bc}	3.4^{b}	1.1^{b}
'Costilluda'	4.5^{a-d}	0.8^{cd}	32.7^{a}	2.0^{b-d}	0.7^{c}	1.1^{c}	0.4^{d}
'Bolsuda'	2.7^{c-e}	0.5^{d}	13.9^{c-e}	0.5^{e}	0.6^{c}	1.5^{c}	0.3^{d}
'Amarilla'	2.6^{de}	0.6^{d}	19.7^{a-d}	2.8^{a-c}	$1.1^{\ bc}$	1.3 c	0.4 d
'Chapilla'	4.6^{a-c}	1.5^{bc}	14.2^{b-e}	3.4^{a}	1.4^{a-c}	2.8^{b}	0.6^{c-d}
'Morada'	5.5^{ab}	1.8^{b}	27.3^{ab}	1.9^{b-d}	1.1^{bc}	4.6^{a}	0.8^{bc}
'Venado'	0.9^{e}	3.0^{a}	6.1^{e}	1.1^{de}	1.0^{bc}	1.4^{c}	0.9^{bc}
'Conservera de Tlaxmalac'	5.7^{a}	2.1^{b}	26.3^{a-c}	2.9^{ab}	2.1^{ab}	5.1^{a}	1.6^{a}
HSD	*1.879*	*0.74*	*13.1*	*1.28*	*0.88*	*1.21*	*0.35*
VC	*36.84*	*17.07*	*27.1*	*25.97*	*26.62*	*13.57*	*16.47*

Same letters in each column indicate statistical similarity according to Tukey's test.

from the Mexican states of Morelos, Guerrero, and Chiapas – a finding that was corroborated in this study.

With regard to color, the following three groups of hues were observed in our sampled fruits: purple and red (hue between 18.3 and 32.1), orange (64.2), and yellow (70.0 to 72.9) (*table II*). Several authors describe the presence of a wide variety of colors, such as red, purple, orange, yellow, and green, in the epicarps of fruits collected from the states of Veracruz, Michoacán and Yucatán, México [6–8, 19]. In *Spondias purpurea*, such colors can be mainly attributed to the presence of phenolic compounds and carotenoids [11].

As for the TSS content of fruit, a maximum value of 18.2 °Brix was found in samples obtained from the ecotype 'Conservera de Tlaxmalac', which was higher than any of the values reported by other authors [6, 7, 19] for ecotypes collected from southern and western Mexico (15.6 and 17.7 °Brix, resp.). However, values of up to 21.1 °Brix have been reported in Mexican plum fruit from the state of Yucatan [8] while values as low as 9.4 °Brix have also been found, specifically in the ecotype "Bolsuda" (*table II*). In a study that analyzed only mature fruit from the state of Veracruz, Nava and Uscanga [27] found the TSS content to range between 13.0 and 18.0 °Brix.

3.2 Total sugar content

In terms of total sugars, the ecotypes 'Conservera de Tlaxmalac' and 'Chapilla" consistently showed the highest average concentrations (185.9 and 177.9 mg g^{-1} FW, resp.), with 'Bolsuda' and 'Costeña' exhibiting the lowest (101.6 and 111.15 mg g^{-1} FW, resp) (*table II*). In *Spondias purpurea* from Brazil, the total content of sugars is reported to range between 44 and 187 mg g^{-1} [28], while in fruits from Ecuador, values between 60 and 72 mg g^{-1} sucrose, 25 mg g^{-1} fructose, 2 mg g^{-1} glucose, and 8 mg g^{-1} reducing sugars, have been reported [10]. The ecotypes analyzed in this study, therefore, present higher values of total sugars than fruits from either Brazil or Ecuador.

3.3 Total phenolic content

The total concentration of phenols was always higher in the fruit epicarp (average 3.7 mg g^{-1} FW) than in the pulp, where values were, generally, up to three times lower (average of 1.3 mg g^{-1} FW) (*table III*). These results coincide with the observations of Engels *et al.* [39] who found, in preliminary investigations, higher phenol concentrations in fruit epicarp than in pulp from genetic materials developed in Costa Rica. 'Conservera de Tlaxmalac' had the highest concentration of phenols out of all the samples of fruit epicarp examined, with 'Morada de Cocula', 'Conservera', and 'Chapilla' displaying intermediate concentrations. Similarly, ecotype 'Venado' showed the highest concentration of phenols out of all the analyzed pulp samples (*table III*), with 'Conservera de Tlaxmalac' and 'Morada' still exhibiting relatively high concentrations in this category (*table III*). Almeida *et al.* [11] and Zielinski *et al.* [40] described total phenol concentrations varying from 0.31 to 0.55 mg g^{-1} FW in Mexican plum fruit from Brazil, while both Cunha *et al.* [28] and Vasco *et al.* [29] reported values between 2.2 and 6.7 mg g^{-1} – similar to the ones obtained in the present work. Comparatively, in mango, guava, papaya, and banana, total phenol concentrations ranging from 0.14 to 1.13 mg g^{-1} have been reported [30] which are below the average values obtained for the pulp and rind of the Mexican plum ecotypes we examined. Engels *et al.* [39] identified 21 phenols in *Spondias purpurea* cultivated in Costa Rica among them, phenolic acids and O-flavonol-glucosides are specially important because evidences of their benefits in human health have increased in the last years. The evaluation of phenol profiles in seeds and leaves, and in other genotypes was recommended by the same authors in order to establish similarities and differences in phenolic composition in other plant structures and fruit with different genetic characteristics.

3.4 Total carotenoid content

The concentration of carotenoids in the rind and pulp of Mexican plum fruit was likewise different, being much higher in the former than in the latter. In particular, the yellow epicarp from ecotype ‘Costilluda’ characteristically displayed the highest average concentrations, while the epicarp from ecotype ‘Venado’ exhibited the lowest (*table III*). For pulp, the highest concentrations were found in the ecotype ‘Chapilla’ while the lowest in ‘Bolsuda” (*table III*). It is reported that the carotenoid content in mango ranges from 0.9 to 11.0 mg 100 g^{-1} FW, but some cultivars like ‘Alphonso’, ‘Willard’, and ‘Karutha Colomban’ have values between 6.3 and 11.0 mg 100 g^{-1} FW [31]. By comparison, the carotenoid content of the Mexican plum ecotypes that we examined ranged from 7.2 to 35.0 mg 100 g^{-1}, if the content from both the rind and pulp are added together (*table II*). This indicates that Mexican plum fruits are a good source of carotenoids, especially when considering that they are generally not peeled and are, for the most part, eaten whole. Zielinski *et al.* [40] indicated that frozen pulp of *Spondias purpurea* had a content of 1.08 mg 100 g^{-1} β-carotene and 1.32 mg 100 g^{-1} licopene. No data concerning the carotenoid profile of pulp and epicarp of Mexican plum fruit have been reported. However, in fruit cultivated in Brazil of the related species *Spondias mombin* L., Tiburski *et al.* [41] identified the following carotenoids: β-cryptoxanthin, lutein, zeinoxanthin, and α- and β-carotene.

3.5 Vitamin C

In the case of vitamin C, concentrations were observed to range from 0.6 to 2.1 mg g^{-1} FW in the examined ecotypes of Mexican plum (*table III*). ‘Gorda’ and ‘Conservera de Tlaxmalac’ had the highest concentrations, followed by ‘Chapilla’ and ‘Costeña’; on the other hand, the ecotypes with the lowest content were ‘Bolsuda’ and ‘Costilluda’ (*table III*). Koziol an Macia [10] quantified between 0.26 and 0.73 mg g^{-1} ascorbic acid in fruits of *Spondias purpurea* from Ecuador, while Cunha *et al.* [28] reported 0.34 to 0.46 mg g^{-1} in fruits from Brazil. By comparison, Almeida *et al.* [11] and El-Otmani *et al.* [32] reported between 0.71 and 0.53 mg vitamin C g^{-1} FW in orange (*Citrus sinensis*), which is traditionally one of the most popularly consumed source of ascorbic acid.

Vitamin C is an essential nutrient for humans and an important antioxidant compound that forms part of our daily diet. Not only it is required for a number of essential metabolic reactions, but it is also an important agent against oxidative stress. It additionally has a role in reducing the tocopheryl radical back to its active form in the membranes of cells [33] and has even been found to have anticancer effects [34]. The ecotypes of Mexican plum evaluated in the present study constitute important sources of vitamin C for the human populations in the production areas.

3.6 Antioxidant activity

The total antioxidant capacity is an estimate of the antioxidant content as well as of the nutraceutical quality of a food and constitutes the biological activity that is, for the most part, responsible for the preventive effect against oxidative damage [35]. The antioxidant activity in Mexican plum fruit was always higher in the epicarp than in the pulp. Similarly, Ahmed *et al.* [42] reported a higher antioxidant activity in the epicarp than in the pulp of *Lagenaria siceria* fruits and they explained that the abundance of phenols in the epicarp was the reason of this difference. The ecotype with the highest content of antioxidant activity present on either epicarp or pulp was ’Conservera de Tlaxmalac’ with 5.1 mM antioxidant capacity equivalent to concentration of ascorbic acid (ACECA) g^{-1} FW in the rind and 1.6 mM ACECA g^{-1} FW in the pulp. The ecotypes with the lowest content of antioxidant activity equivalents were ’Costilluda’ with 1.09 mM in the rind and ’Bolsuda’ with 0.34 mM ACECA g^{-1} FW in the pulp. On average, the antioxidant capacity that was measured in the ecotypes examined was 3.0 mM ACECA g^{-1} FW in the rind and 0.7 mM ACECA g^{-1} FW in the pulp (*table III*). Floegel *et al.* [43] found antioxidant activities (in equivalents of vitamin C) ranging from 6.8 to 521.0 mg 100 g^{-1} FW when they analyzed the 18 most consumed fruits in the United States; unfortunately, they did not indicate if the assays were conducted in the pulp or the whole fruit (peel and pulp). However, the values found in the present study are in the range reported by these authors (on average, 123 and 528 mg 100 g^{-1}FW equivalent to vitamin C for pulp and rind, respectively).

Thus, the contribution of *Spondias purpurea* fruit to the diet, in terms of antioxidant capacity, is higher than for other fruits, especially when consumers eat not only the pulp but also the peel of Mexican plum. Humans have antioxidant enzyme systems that evolved over thousands of years and are dependent on a number of vitamins and minerals from our diet. Also, some nutrients such as vitamin E, vitamin C, β-carotene, and other bioactive compounds, notably lycopene and polyphenols, possess antioxidant activity without necessarily being associated to any enzyme [36]. There exist a large number of such compounds in our diet, mainly polyphenols, which are the most abundant antioxidants. Their intake can be as high as 1 g per person and per day, making their consumption several times higher than that of any other antioxidant [37].

3.7 Statistical correlations

The relationship between the antioxidant capacity of the rind and pulp was negative with respect to the color variables L*, C*, and h *(table IV*), suggesting that fruits presenting a low lightness red or purple coloration in their epicarps generally exhibit the highest values of antioxidant activity. Positive and significant associations were observed between TSS and total sugars, total phenols in the rind, total carotenoids in the pulp, and the antioxidant activities in the epicarp and pulp *(table IV*). Likewise, similar correlations were observed between TA and all of the aforementioned variables *(table IV*).

Among the different Mexican plum ecotypes examined, positive correlations could be established between the antioxidant activities of both the rind and pulp and the total phenols present in the rind. The antioxidant activity of the rind was also significantly correlated with the content of vitamin C *(table IV*).

The above results indicate that the fruits with the highest content of TSS, sugars, total phenolics, and vitamin C

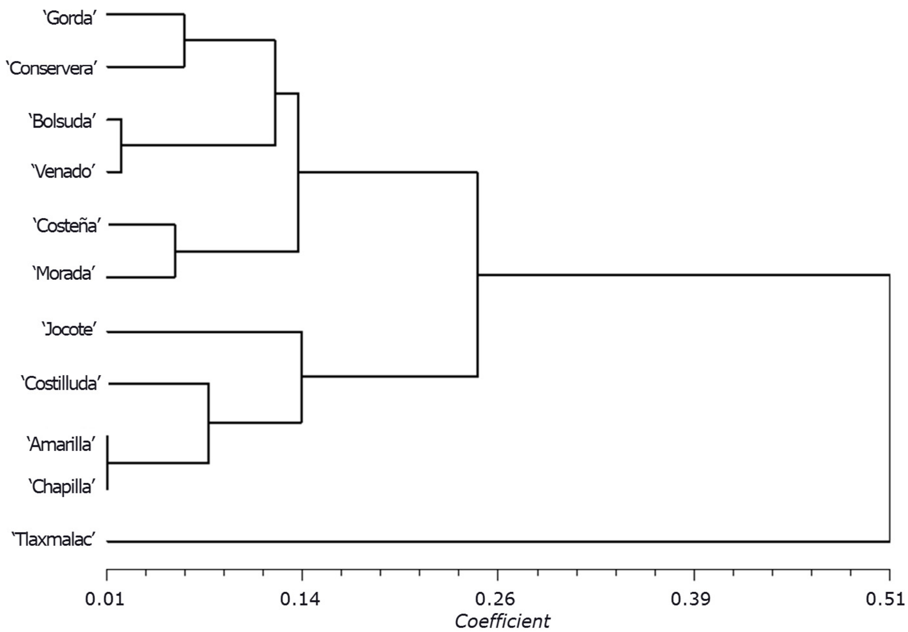

Figure 1. Dendrogram of the 11 evaluated ecotypes of Mexican plum fruit (*Spondias purpurea* L.) built using the UPGMA method (average linkage) based on 15 fruit attributes. The distance coefficient refers to the Taxonomic Distance.

Table IV. Statistical correlations between quality attributes of the 11 evaluated ecotypes of Mexican plum fruit (*Spondias purpurea*). L* = lightness (0-white; 100-black); C*: chroma (vivid-opaque); h: hue angle (0-red; 90-yellow); TSS: total soluble solids (°Brix); TS: total sugars (mg g^{-1} FW); PE: phenols in epicarp (mg g^{-1} FW); PP: phenols in pulp (mg g^{-1} FW); CE: carotenoids in epicarp (mg 100 g^{-1} FW); CP: carotenoids in pulp (mg 100 g^{-1} FW) VIT C: Vitamin C in fruit (mg ascorbic acid g^{-1} FW); AAE and AAP: antioxidant activity in epicarp and pulp respectively (mM ascorbic acid g^{-1} FW).

Variable	Correlation coefficient (r)	Variable	Correlation coefficient (r)
L*C*	0.79***	TSS*AAE	0.55**
L*h	0.94***	TSS*AAP	0.49**
L*AAE	–0.57**	TS*PE	0.48**
L*AAP	–0.58**	TS*PP	0.56**
C*h	0.65***	TS*CE	0.36*
C*CE	0.35*	TS*CP	0.67***
C*AAE	–0.33*	TS*AAP	0.46**
C*AAP	–0.44**	PE*CE	0.41**
h*CP	0.49**	PE*CP	0.36*
h*AAE	–0.51**	PE*AAE	0.50**
h*AAP	–0.44**	PE*AAP	0.40**
TSS*TS	0.52**	PP*CE	0.54**
TSS*PE	0.39*	CE*CP	0.41**
TSS*CP	0.41**	VIT C*AAE	0.51**
TSS*VIT C	0.62***	AAE*AAP	0.53**

*, **, ***: Significant correlation at $P < 0.05$, 0.01, 0.0001, respectively.

would provide the greatest benefit to human health, given that they exhibit the greatest antioxidant capacity in both rind and pulp. Some nutrients such as vitamin C, β-carotene, and bioactive compounds such as polyphenols, act as antioxidant agents against oxidative stress. It is noteworthy to mention that polyphenol compounds confer rich, saturated colors to foods, often with different shades or lightness characteristics, making them appear attractive to consumers, such as in the case of *Spondias purpurea* fruit.

Therefore, the highest antioxidant capacity can be found in fruits whose epicarp presents a red, purple, or dark purple color at consumption maturity (ripe stage), such as that from the ecotypes'Conservera de Tlaxmalac' or 'Morada'. These in turn, also tend to have the highest content of phenols and carotenoids, suggesting that such compounds probably contribute to their high antioxidant capacity. The consumption of these fruits could therefore contribute to the prevention of cancer, arthritis, and chronic degenerative diseases associated with aging, such as Alzheimer and Parkinson diseases [11].

3.8 Cluster analysis

Six different groups could be resolved at an average taxonomic index of 0.104 (*figure 1*). Group 1 was formed by the ecotypes'Gorda' and 'Conservera' from the state of Guerrero and consisted of fruits with a low-lightness red color, medium mass, a high content of vitamin C, a high antioxidant capacity (in both rind and pulp), and an important concentration of phenols and total sugars (*table V*). Group 2 included the ecotypes'Bolsuda' and'Venado', both also from the state of Guerrero (*figure 1*), whose parameters for color, and values of total sugars and carotenoids, were similar to the previous group. Nevertheless, their content of phenols, vitamin C, and antioxidant capacities were lower than those of Group 1 (*table V*). Group 3, similarly, consisted of 2 ecotypes, 'Costeñ' and'Morada', with fruits characterized by having a high mass, a low-lightness red color, an intermediate content of TSS, total

Table V. Average values of the 13 quality attributes evaluated in the six groups of Mexican plum fruit ecotypes (*Spondias purpurea*) formed by cluster analysis. L* = lightness (0-white, 100-black); C*: chroma (vivid-opaque); h: hue angle (0-red, 90-yellow); TSS: total soluble solids (°Brix); TS: total sugars (mg g^{-1} FW); PE: phenols in epicarp (mg g^{-1} FW); PP: phenols in pulp (mg g^{-1} FW); CE: carotenoids in rind (100 mg g^{-1} FW); CP: carotenoids in pulp (mg 100 g^{-1} FW); VIT C: Vitamin C in fruit (mg ascorbic acid g^{-1} FW); AAE and AAP: antioxidant activity in epicarp and pulp resp (mM acorbic acid g^{-1} FW).

GROUP	Mass	L*	C*	h	TSS	TS	PE	PP	CE	CP	VIT C	AAE	AAP
1	14.01	33.17	36.60	23.97	16.18	2.92	4.40	0.94	8.11	0.81	1.43	4.11	0.83
2	12.81	36.00	41.70	31.19	11.88	2.78	1.83	1.74	10.01	0.79	0.83	1.47	0.60
3	17.49	34.82	39.98	28.11	14.31	3.01	4.12	1.35	22.95	1.28	1.23	4.33	0.67
4	34.82	54.02	51.56	71.73	13.93	2.67	2.25	1.03	7.57	1.58	0.65	3.36	0.79
5	12.06	52.15	49.11	69.06	14.79	3.37	3.91	0.95	22.19	2.75	1.07	1.73	0.49
6	12.54	31.38	39.69	26.36	18.23	4.20	5.73	2.12	26.26	2.93	2.07	5.15	1.63

Table VI. Eigenvalues and proportion of total variance explained by the principal components based on the correlation matrix applied to 13 physical and biochemical characteristics in the 11 evaluated ecotypes of Mexican plum fruit (*Spondias purpurea*).

Principal component	Eigenvalue	Proportion of explained variance (%)	
		Absolute	Cumulative
1	7.0764	47.1760	47.1760
2	2.8802	19.2013	66.3773
3	1.5302	10.2020	76.5793

Table VII. Eigenvalues and degree of participation of 13 characteristics on the first three principal components (PC), based on the correlation matrix applied to the 11 evaluated ecotypes of Mexican plum fruit (*Spondias purpurea*). Figures in bold are the most differentiating attributes.

Original variable	Eigenvectors		
	PC1	PC2	PC3
Mass	0.2449	**0.6619**	0.0320
Lightness (L*)	–0.1308	**0.8689**	0.3493
Chroma (C*)	0.3988	**0.5521**	0.2438
Hue angle (h)	**–0.8756**	–0.1865	–0.1145
Total soluble solids	**0.7015**	0.4410	–0.1665
Total sugars	**–0.9410**	0.1447	–0.0203
Phenols in epicarp	–0.0412	–0.0062	**0.4935**
Phenols in pulp	**–0.9032**	0.1035	–0.1081
Carotenoids in epicarp	0.3841	**–0.6072**	0.4833
Carotenoids in pulp	**–0.9414**	–0.2882	–0.1601
Vitamin C	**–0.9211**	0.1688	–0.2407
Antioxidant activity in epicarp	0.1283	**0.6050**	–0.5051
Antioxidant activity in pulp	**–0.9686**	0.1059	–0.0654

sugars, phenols (in the rind), and vitamin C, as well as a high antioxidant activity in the rind (*table V*).

'Jocote', from the state of Chiapas, was the only ecotype found in Group 4. Its fruit had the highest mass of all that were evaluated and, despite having a low content of carotenoids in both rind and pulp, its hue angle was nevertheless measured as being close to yellow. This ecotype also showed a low content of sugars, phenols, vitamin C, and antioxidant activity (*table V*). The ecotypes'Costillluda', 'Amarilla', and 'Chapilla', on the other hand, all clustered in Group 5 (*figure 1*). Their fruits were orange to yellow in color, had a low mass, intermediate amounts of total sugars, a low content of phenols in the rind, and a high content of carotenoids in both rind and pulp (*table V*). Lastly, Group 6 was the only other group that, just like Group 4, consisted of only one ecotype, in this case 'Conservera de Tlaxmalac', which was characterized by having high concentrations of TSS, phenols, carotenoids, and vitamin C, together with a high antioxidant activity (*table V*).

An analysis of principal components indicated that PC1, PC2, and PC3 explained 47.1, 19.2, and 10.2% of the variability respectively, and that cumulatively, they explained 76.5% of the total variability (*table VI*). PC1 was defined by hue, the content of total sugars, phenols, and carotenoids in pulp, the antioxidant capacity in the pulp, and the content of vitamin C in both the rind and pulp (*table VII*). PC2 on the other hand, was defined by the mass of the fruit, the L* and C* color parameters, and the antioxidant activity of the rind. Lastly, PC3 was exclusively defined by the total content of phenols in the rind. When evaluating 67 samples of *Spondias purpure*a fruit from southern Mexico, Alia-Tejacal *et al.* [19] determined that the mass, size, and color of the fruit epicarp allowed the formation of different groupings. The present work shows that the content of sugars, pigments in the pulp, vitamin C, and antioxidant capacities in both rind and pulp, were the main parameters that lead to the specific groupings observed in the ecotypes evaluated. This is important for subsequent evaluations of *Spondia*s features, as the parameters used in the present study can be applied as selection criteria for future breeding programs.

4 Conclusion

Significant variations were observed in the chemical and physical characteristics of the 11 different ecotypes of Mexican plum fruit that were examined, and there was a high correlation between the total content of phenols present in the rind and the antioxidant capacities measured in both rind and pulp (r = 0.5**). Additionally, it was determined that the ecotype 'Conservera de Tlaxmalac', had the best quality attributes (phenols, total carotenoids, and antioxidant capacity) out of all the fruits that were analyzed. This is making it particularly attractive for fresh consumption as it would provide a relatively high content of essential nutrients and functional biomolecules, which could in turn, prove beneficial to human health.

Acknowledgements. The authors would like to thank the generous financial support from SEP-PROMEP to the research network "*Ciencia y Tecnología Pre y Postcosecha*" (Pre and Postharvest Science and Technology) for the completion of the present study. We would also like to thank B. Sc. Leonardo Castillo Pelayo for his assistance in the revision of the English language manuscript.

References

[1] Morton J., Purple mombin, in: Morton JF. (Ed.), Fruits of warm climates, Miami, Fl., 1987, pp. 242–245.

[2] Pennington D.T., Sarukhán J., Árboles tropicales de México, Manual para la identificación de las principales especies, UNAM-FCE. Tercera Edición, México, D.F., 2005, 523 p.

[3] Avitia G.E., Castillo G.A., Pimienta B.E., Ciruela mexicana y otras especies del genero *Spondias* L. Universidad Autónoma Chapingo. Chapingo, Estado de México, 2000, 75 p.

[4] Cuevas J. Jocote, ciruelo (*Spondias purpurea*), in: Organización de las Naciones Unidas para la Agricultura y la Alimentación (FAO) Cultivos Andinos Subexplotados y su Aporte a la Alimentación, Santiago, 1992, pp. 109–113.

[5] Maldonado-Astudillo Y.I., Alia-Tejacal I., Núñez-Colín C.A., Jiménez-Hernández J., López-Martínez V., Valle-Guadarrama S., Andrade-Rodríguez M., Bautista-Baños S., Pelayo-Zaldívar C., Postharvest physiology and technology of *Spondias purpurea* L. and *S. mombin* L., Sci. Hortic. 174 (2014) 193–206.

[6] Ramírez H.B.C., Pimienta B.E., Castellanos R.J.Z., Muñoz U.A., Palomino H.G., Pimienta B.E., Sistemas de producción de *Spondias purpurea* (Anacardiaceae) en el centro-occidente de México, Rev. Biol. Trop. 56 (2008) 675–687.

[7] Pérez-Arias G.A., Alia-Tejacal I., Andrade-Rodríguez M., López-Martínez V., Pérez-López A., Ariza-Flores R., Sánchez M.A.O., Villarreal F.J.M., Características físicas y químicas de ciruelas mexicana (*Spondias purpurea*) en Guerrero, Inv. Agropec. 5 (2008) 141–149.

[8] Ruenes-Morales M.R., Casas A., Jiménez-Osornio J.J., Caballero J., Etnobotánica de *Spondias purpurea* L. (Anacardiaceae) en la península de Yucatán, Interciencia 35 (2010) 247–254.

[9] Díaz-Pérez J.C., Zavaleta R., Bautista B.S., Aguilar V.S., Cambios físico-químicos de ciruela mexicana (*Spondias purpurea* L.) cosechada en dos diferentes estados de madurez, Rev. Iber. Tecnol. Postcosecha, 2 (1999) 19–24.

[10] Koziol M.J., Macía M.J., Chemical composition, nutritional evaluation, and economic prospects of *Spondias purpurea* (Anacardiaceae), Econ. Bot. 52 (1998) 373–380.

[11] Almeida M.M.B., de Sousa P.H.M., Arriaga Â.M.C., do Prado G.M., Magalhães C.E.D.C., Maia G.A., de Lemos T.L.G., Bioactive compounds and antioxidant activity of fresh exotic fruits from northeastern Brazil, Food Res. Int. 44(7) (2011) 2155–2159.

[12] Ali S., Kasoju N., Luthra A., Singh A., Sharanabasava H., Sahu A., Indian medicinal herbs as sources of antioxidants, Food Res. Int. 41 (2008) 1–15.

[13] Serrano J., Goni I., Saura-Calixto F., Food antioxidant capacity determined by chemical methods may underestimate the physiological antioxidant capacity, Food Res Int. 40 (2007) 15–21.

[14] Tadhani M.B., Patel V.H., Subhash R., *In vitro* antioxidant activities of *Stevia rebaudiana* leaves and callus, J. Food Compost Anal. 20 (2007) 323–329.

[15] Moon J.K., Shibamoto T., Antioxidant assays for plant and food components, J. Agric. Food. Chem. 57 (2009) 1655–1666.

[16] Moure A., Cruz J.M., Franco D., Domínguez J.M., Sineiro J., Domínguez H., Natural antioxidants from residual sources, Food Chem. 72 (2001) 145–171.

[17] Kuskoski E.M., Asuero A.G., Troncoso A.M., Mancini-Filho J., Fett R., Aplicación de diversos métodos químicos para determinar actividad antioxidante en pulpa de frutos, Cienc. Tecnol. Aliment. 25 (2005) 726–732.

[18] Mahattanatawee K., Manthey J.A., Luzio G., Talcott S.T., Goodner K., Baldwin E.A., Total antioxidant activity and fiber content of select Florida-grown tropical fruits, J. Agric. Food Chem. 54 (2006) 7355–7363.

[19] Alia-Tejacal I., Astudillo-Maldonado Y.I., Núñez-Colín C.A., Valdez-Aguilar L.A., Bautista-Baños S., García-Vázquez E., Ariza-Flores R., Rivera-Cabrera F., Fruit characterization of Mexican plum *(Spondias purpurea*) from southern México, Rev. Fitotec. Mex. 35 (2012) 21–26.

[20] McGuire R.G., Reporting of objective color measurements, HortScience 27 (1992) 1254–1255.

[21] Whitham F.H., Blaydes D.F., Devlin R.M., Experiments in plant physiology, Van Nostrand Reinhold Company, New York, 1971, pp. 55–58.

[22] Waterman P.G., Mole S., Analysis of phenolic plant metabolites, Osney Mead, Oxford, England, 1994, 235 p.

[23] Alia T.I., Colinas-León M.T., Martínez-Damián M.T., Soto-Hernández M.R., Factores fisiológicos, bioquímicos y de calidad en frutos de zapote mamey (*Pouteria sapota* Jacq. H. E: Moore & Stearn) durante poscosecha, Rev. Chapingo S. Hort. 8 (2002) 263–281.

[24] Rodríguez-Amaya D.B., Kimura M., Harvest Plushanbook for carotenoid analysis, Harvest Plus technical Monograph 2, Washington DC y Cali, International Food Policy Research Institute and International Center for Tropical Agriculture, 2004, 53 p.

[25] Jagota S., Dani H., A new colorimetric technique for estimation of vitamin C using folin phenol reagent, Anal. Biochem. 127 (1982) 178–182.

[26] Brand-Williams W., Cuvelier M.E., Berset C., Use of free radical method to evaluate antioxidant activity, Lebensm. Wiss. Technol. 28 (1995) 25–30.

[27] Nava K.G., Uscanga B.M., Estudio físico y químico de doce tipos de ciruela (*Spondias* sp.) en el estado de Veracruz, Proc Tropical Region ASHS 23 (1979) 132–136.

[28] Cunha F.H.A., Elesbao A.R., Herbster M.C.F., Cordeiro de O.A., Costa Araújo N.C., Calidad de frutas nativas de Latinoamérica para industria: ciruela mexicana (*Spondias purpurea* L.), Proc. Interamer. Soc. Trop. Hort. 43 (2001) 67–71.

[29] Vasco C., Ruales J., Kamal-Eldin A., Total phenolic compounds and antioxidant capacities of major fruits from Ecuador, Food Chem. 111 (2008) 816–823.

[30] Oruma P., Prapasri P., Anadi N., Prapaisri P.S., Changes of antioxidant activity and total phenolic compounds during storage of selected fruits, J. Food Compost. Anal. 21 (2007) 241–248.

[31] Thanaraj T., Terry L.A., Tropical Fruit [Banana, Pineapple, Papaya and Mango], In: Terry A.L. (Ed.), Health-promoting properties of fruit & vegetables, CABI Publishing, 2011, pp. 352–370.

[32] El-Otmani M., Ait-Oubahou A., Zacarias L., *Citrus* spp.: orange, mandarin, tangerine, Clementine, grapefruit, pomelo, lemon and lime, in: Yahia E. (Ed.), Postharvest biology and technology of tropical and subtropical fruits, Woodhead Publishing, Vol 2, Acai to citrus, 2011, pp. 437–514.

[33] Klimczak I., Malecka M., Szlachta M., Gliszczynska-Swiglo A., Effect of storage on the content of polyphenols, vitamin C and the antioxidant activity of orange juices, J. Food Compost Anal. 20 (2007) 313–322.

[34] Kim D.O., Lee K.W., Lee H.J., Lee C.Y., Vitamin C equivalent antioxidant capacity (VCEAC) of phenolic phytochemicals, J. Agric. Food Chem. 50 (2002) 3713–3717.

[35] Heo H.H., Kimb Y.J., Chung D., Kimbd D., Antioxidante capacities of individual and combined phenolics in a model system, Food Chem. 104 (2007) 87–92.

[36] Edge R., McGarvey D.J., Truscott T.G., The carotenoids as antioxidants- a review, J. Photochem. Photobiol. 41 (1997) 189−200.

[37] Manach C., Scalbert A., Morand C., Rémés C., Jiménez L., Polyphenols: food sources and bioavailability, Am. J. Clin. Nutr. 79 (2004) 727–747.

[38] De Ritter, E. and A.E. Purcell. 1981. Carotenoid analytical methods, p. 815–923, in: J.C. Bauernfeind (Ed.). Carotenoids as colorants and vitamin precursors, Academic Press, New York.

[39] Engels C., Gräter D., Esquivel P., Jiménez V.M., Gänzle M.G., Schieber A., Characterization of phenolic compounds in jocote (*Spondias purpurea* L.) peels by ultra high-performance liquid chromatography/electrospray ionization mass spectrometry, Food Res. Int. 46 (2012) 557–562.

[40] Zielinski A.A.F., Ávila S., Nogueira A., Wosiacki G., Haminiuk C.W.I., The association between chromaticity, phenolics, carotenoids, and *in vitro* activity of frozen fruit pulp in Brazil: an application of chemometrics, Food Chem. 79 (2014) C510−C516.

[41] Tiburski J.H., Rosenthal A., Deliza R., de Oliveira Godoy R.L., Pacheco S., Nutritional properties of yellow mombin (*Spondias mombin* L.) pulp, Food Res. Int. 44 (2011) 2326–2331.

[42] Ahmed D., Fatima M., Saeed S., Phenolic and flavonoid contents and anti-oxidative potential of epicarp and mesocarp of *Lagenaria siceraria* fruit: a comparative study, Asian Pac. J. Trop. Med. 7 (2014) S249–S255.

[43] Floegel A., Kim D.-O., Chung S.-J., Koo S. I., Chun O.K., Comparison of ABTS/DPPH assays to measure antioxidant capacity in popular antioxidant-rich US foods, J Food Compost Anal 24 (2011) 1043–1048.

Cite this article as: Susana Solorzano-Morán, Irán Alia-Tejacal, Fernando Rivera-Cabrera, Víctor López-Martínez, Laura Josefina Pérez-Flores, Clara Pelayo-Zaldívar, Dagoberto Guillén-Sánchez, Fernando Díaz de León-Sánchez, Yanik Ixchel Maldonado-Astudillo. Quality attributes and functional compounds of Mexican plum (*Spondias purpurea* L.) fruit ecotypes. *Fruits* 70 (2015) 261–270.