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Physical-chemical characteristics and antioxidant potential of seed and pulp of *Ximenia americana* L. from the semiarid region of Brazil

José Darcio Abrantes Sarmento[1]*, Patrícia Lígia Dantas de Morais[1], Francisco Israel de Souza[1] and Maria Raquel Alcântara de Miranda[2]

[1]Departamento de Ciências Vegetais, Universidade Federal Rural do Semi-Árido, CEP 59625-900, Mossoró, Rio Grande do Norte, Brazil.
[2]Departamento de Bioquímica e Biologia Molecular, Universidade Federal do Ceará, Centro de Ciências, CEP 60440-554, Fortaleza, Ceará, Brazil.

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***Ximenia americana* popularly known as wild plum grow wildly in Brazilian semiarid region and its fruit were harvested in two maturity stages and evaluated for quality. The experimental design was completely randomized with three treatments (immature, mature pulp and seeds), and treatment effect was evaluated for pulp fraction (composed of both mesocarp and exocarp or peel) in maturation stages: immature (largest size with green colored peel), mature (largest size with yellow colored peel) and seeds of mature fruits, from eight repetitions of 25 fruits each, totaling 200 fruits per treatment. Fruit were separated and evaluated for physical and physicochemical variables, mineral composition, bioactive compounds content and total antioxidant activity (TAA). The *X. americana* grown in Brazilian semiarid region presents a great potential to further commercial exploitation. The pulp, aside its maturation stage contains high levels of lipids, proteins, sugars, starch, titratable acidity, vitamin C, yellow flavonoids, polyphenols and antioxidant activity. The seed also presents high levels of lipid, protein, starch, total extractable polyphenols and antioxidant activity. Imature pulp stands out for acidity, polyphenol, flavonoid and anthcyanin levels, while mature fruit pulp has higher yield, sugar and vitamin C levels. Seeds have higher starch, protein and lipi levels. The antioxidant activity found for wild plum pulp could be attributed to polyphenol and vitamin C contents; meanwhile, the antioxidant activity of seeds was dependent only on polyphenolic content. Pulp had higher Na, K, Mg, Ca and Fe levels, however, both seed and pulp fractions have substantial contents of P, K, Cu and Mn.**

Key words: Development, bioactive compounds, antioxidant activity, minerals, quality.

INTRODUCTION

A significant part of Brazil's large biodiversity is in the Northeastern semiarid region known as Caatinga, an ecosystem unique to this country. In spite of the large number of plant species present in Caatinga, among those unexploited species is the wild plum, with potential for further commercial exploitation (*Ximenia americana*

Linnaeus).Although, in Brazil, its occurrence is mainly in the semiarid region, it is also found in Africa, India, New Zealand, Central America and in other South American countries (Sacande and Vautier, 2006; Souza, 2008), where reports show it is broadly used in non-traditional medicine (Gronhaug et al., 2008; James et al., 2008; Le et al., 2012).

The consumption of tropical fruits has increased in domestic and foreign markets due to the growing enlightement of their nutritional and therapeutic properties (Rufino et al., 2010). Tropical fruits may present unique sensorial characteristics and high concetrations of nutrients (Souza et al., 2012) especially when it comes to wild or native species (Genovese et al., 2008). These are outstanding sources of antioxidant compounds, which are associated with anti-aging and health promoting properties due to their potential to lower or inhibit oxidative stress (Hassimoto et al., 2005). These antioxidants differ in nature as minerals, dietary fibers, phytochemicals as phenolics and vitamin C and pigments as carotenoids and chlorophyll, which overall are more abundant in immature fruit.

Previous reports show that *X. americana* are rich in antioxidants such as vitamin C and phenolics, thus representing a good source of such compounds for humans (Rezanka; Sigler, 2007; Silva et al., 2008; Lamien-Meda et al., 2008; Mora et al., 2009). Besides the pulp, fruit may also be explored for their seeds yet, another study shows that wild plums seeds are very tasty and have been used as a food spice, despite their purgative effects (Brasileiro et al., 2008).

The characterization of bioactive compounds is important to determine the nutritional quality and commercial value of a fruit and its subproducts. However, the wild plum's potential as source of energy, minerals, carbohydrates, and other bioactive health-promoting compounds have not yet been investigated. Thereby, by characterizing the wild plum and its seed, we hope to enable its commercial exploitation as fresh or processed product, as source of additives and natural ingredients. Thus, this work aimed to characterize the physical, mineral, chemical and antioxidant potential of seed and pulp from *X. americana* grown native to semiarid region of Brazil, as a means to enhance its consumption and production.

MATERIALS AND METHODS

Sample preparation

X. americana plants grow wildly in Mossoró-Assu, RN, Brazilian semiarid region (5° 16'' 52"" S and 37° 11'' 46"" W) where the climate, according to Köppen classification is "BSwh", dry and very hot with two seasons: dry, from June to January and rainy, from February to May (Carmo Filho and Oliveira, 1995). Fruit were harvested on December of 2011, when relative humidity was 62.49%, average temperature was 28°C and rainfall was 28.95 mm, as reported by the weather station of Universidade Federal Rural do Semi-Árido-UFERSA.

Fruit harvested in two maturation stages, immature (largest size with green colored peel) and mature (largest size with yellow colored peel) were selected for uniformity of maturation and no damage marks and then, washed in tap water. Afterwards, fruit in both developmental stages were divided into two fractions, pulp (composed of both mesocarp and exocarp or peel) and seeds. Only mature seeds were evaluated.

For treatment, effect was evaluated for pulp fraction (composed of both mesocarp and exocarp or peel) in maturation stages: immature (largest size with green colored peel) and matures (largest size with yellow colored peel) and seeds of ripe fruits, from 8 repetitions of 25 fruits each, totaling 200 fruits per treatment. Pulp tissue was homogenized in Ultra-Turrax® (IKA, Germany) homogenizer, meanwhile seeds were crushed in a Wiley® stainless-steel (Thomas Sci., USA) mill and both samples were stored in a domestic freezer (-20°C) until the analysis were performed.

Physical characteristics

Evaluations were done with eight replications with 25 fruit each. Fruit were individually measured for their longitudinal and transverse diameters with a digital stainless hardened caliper (Shan, China) to determine shape (Lopes, 1982); fresh mass with an analytical balance (model FA 2104N by Celtac, China), and mass yield of different fractions (seed, peel and pulp) obtained by the difference between total fruit mass and that of the different constituents per si.

Chemical and mineral composition

Humidity was determined as samples were dehydrated at 65°C until reaching a constant weight. Lipid content was determined by Soxhlet extraction method and ashes were determined at 550°C according to Silva and Queiroz (2002). Protein content was determined by Kjeldahl method using a conversion factor of 6.25 (Silva, 2009). pH was determined using a pH meter (Model mPA-210 by Tecnal®, Brazil) with automatic temperature adjustment as described by AOAC (2002). Titratable acidity was determined according to AOAC (2002) using an automatic titrator (Titrette® model Class A precision by BRAND, USA) and results were expressed as mEq H_3O^+/100 g. Soluble solids were determined with a digital refractometer (Palette model PR – 100, by Atago, Japan) (AOAC, 2002). Total sugar content determined by the anthrone (Vetec, Brazil) method according to Yemn and Willis (1954), reducing sugars by DNS (3,5-dinitro salicylic acid, Vetec, Brazil) method according to Miller (1959) and starch content according to the method of AOAC (2002) and Miller (1959). Absorbances were monitored with UV-VIS spectrophotometer (model UV-1600 by Pró-Análise®, Brazil).

Minerals were quantified as following: potassium and sodium

*Corresponding author. E-mail: darcioabrantes@yahoo.com.br; plmorais@ufersa.edu.br. Tel: +55 84 3317-8538.

by flame emission photometer and phosphorus by spectrophotometry (model SP 1105 by BEL Photonics, Brazil). Calcium, magnesium, copper, manganese and iron were determined by atomic absorption spectrophotometry (model AA240FS by Varian, USA) after nitric acid was submitted to microwave (MD3113 series by CEM II®, USA) digestion of organic matter (Silva, 2009). Results were expressed on fresh weight basis. All other reagents were of analytical grade and were also supplied by Vetec, Brazil.

Bioactive compounds content

The total vitamin C was determined by titration with 0.02% 2,6-dichloro-indophenol (DFI) (as proposed by Strohecker and Henning (1967). One gram of pulp was diluted to 100 mL of 0.5% oxalic acid and homogenized. Then, 5 mL of this solution was diluted to 50 mL with distilled water and titrated and results were expressed as mg/100 g FW (fresh weight).

Anthocyanins and yellow flavonoids were extracted and determined as described by Francis (1982). One gram of pulp was extracted with a 95% ethanol/1.5 N HCl (85:15) solution, vortexed for 2 min and then, brought to 50 mL with the extracting solution. Protected from the light, the mixture was refrigerated at 4°C for 12 h, then filtered on Whatman N.1 paper and the filtrate was gathered. The absorbance of the filtrate was measured at 535 nm for the total anthocyanin content using an absorption coefficient of 98.2 mol/cm and at 374 nm for the total yellow flavonoid content using an absorption coefficient of 76.6 mol/cm. Both results were expressed as mg/100 g FW.

The total phenol content of acerola was measured by a colorimetric assay using Folin-Ciocalteu reagent as described by Obanda and Owuor (1997). Before the colorimetric assay, the samples were subjected to extraction in 50% methanol and 70% acetone as described by Larrauri et al. (1997). Extracts were added to 1 mL Folin Ciocalteau reagent (1 N), 2 mL Na_2CO_3 at 20% and 2 mL of distilled water. Results were expressed as gallic acid equivalents (GAE) mg/100 g FW.

Total carotenoids were measured as described by Higby´s (1962). Five grams of pulp were homogenized with 15 mL alcohol and 5 mL hexane and then, let to stand for 90 min. The mixture was filtered into a 25 mL flask, then 2.5 mL acetone was added and volume completed with hexane. Absorbance was monitored at 450 nm and results were expressed as mg/100 g FW.

Total antioxidant activity - $ABTS^{\bullet+}$ assay

The total antioxidant activity (TAA) was determined using 2,2-azinobis-3-ethylbenzthiazoline-6-sulphonic acid radical cation ($ABTS^{\bullet+}$, Sigma) method as described by Miller et al. (1993). Before the colorimetric assay, the samples were subjected to a procedure of extraction in 50% methanol and 70% acetone. Once the radical was formed, the reaction was started by adding 30 µL of extract in 3 mL of radical solution, absorbance was measured (734 nm) after 6 min and the decrease in absorption was used to calculate the total antioxidant activity (TAA). A calibration curve was prepared and different trolox concentrations (standard trolox solutions ranging from 100 to 2000 µM) were also evaluated against the radical. Antioxidant activity was expressed as trolox equivalent antioxidant capacity (TEAC), µmol trolox/g FW.

Total antioxidant activity - $DPPH^{\bullet}$ assay

The free radical-scavenging by DPPH assay is based on the sequestering of DPPH radical (2,2-diphenyl-1-picryl-hydrazyl, Sigma) by antioxidants, decreasing absorbance at 515 nm and was proposed by Brand-Williams et al. (1995) and modified by Sánchez-Moreno et al. (1998). A methanol solution containing 0.06 mM DPPH was prepared and aliquots of 100 mL were added and absorbance monitored at 515 nm, until stabilization (110 min for immature fruit pulp, 85 min for mature and 30 min for seed 30). The antioxidant activity was expressed as the concentration of antioxidant able to reduce the free radicals by 50% (EC_{50}) and expressed in g /g DPPH.

Statistical analysis

The experimental design was completely randomized with 3 treatments (immature, mature pulp and seeds) with eight replicates consisting of 25 fruit, each, totaling 200 fruits per treatment. The data obtained was subjected to analysis of variance (ANOVA) using a Sisvar 5.1 Build 72 program (Ferreira, 2011) and the means were compared by the Tukey test at 5% probability. Pearson's correlation analysis to the 5% level of significance between mean values found for bioactive compounds and total antioxidant activity during maturation was performed using BioEstatística 5.0 program.

RESULTS AND DISCUSSION

Physical analysis

There was significant differences between the physical characteristics evaluated (Table 1). There was a statistical difference for the physical characteristics evaluated for yield ripe fruit highlighted with higher value (Table 1). *X. americana* fruit here evalauted were yellow-orange drupes when mature and green colored when immature with an aromatic bittersweet pulp involving a seed with white nut. The values for transversal diameter were slightly lower than longitudinal diameter indicatives of an spherical shape (0.9 ≤ ratio ≤ 1.1), while the seeds were oblong (1.1 < ratio ≤ 1.7) (Table 1).

For local population, the yellow colored fruit is regarded mature when it is rounded in shape and present a characteristic aroma. Immature fruits presented an average weight of 4.5 g, while mature average mass was 4.4 g, the seeds weighted 0.89 g and pulp consisting of mesocarp and exocarp constituted the main portion yielding an average of 78.55% for immature fruits and 79.87% for mature fruits (Table 1). As fruit ripens, mass and yield increase and seeds correspond to approximate 20% of whole fruit mass. Mora et al. (2009) reported that wild plums from Mexico presented the same rounded shape with mass ranging from 4.2 to 6.5 g, mesocarp and exocarp yield ranges between 70.8 and 78.4% while seeds were from 29.2 to 21.6%.

Chemical composition

There was a significant difference for all variables evaluated

Table 1. Physical characterization of *Ximenia americana* from the semiarid region of Brazil.

Variable	Seed	Pulp	
		Immature	Mature
Longitudinal diameter (mm)	13.57 ± 0.60[b]	18.60 ± 0.65[a]	18.51 ± 0.38[a]
Transversal diameter (mm)	10.42 ± 0.27[b]	17.88 ± 0.45[a]	17.61 ± 0.57[a]
Format (Ratio LD/TD)	1.30 ± 0.07[a]	1.04 ± 0.03[b]	1.05 ± 0.03[b]
Fresh mass (g)	0.89 ± 0.08[b]	4.57 ± 0.58[a]	4.43 ± 0.41[a]
Yield (%)	20.13 ± 0.56[c]	78.55 ± 1.33[b]	79.87 ± 0.56[a]

The same letters in the same row indicate no significant difference at a level by the Tukey test at 5% probability. Data expressed as mean values ± standard deviation.

Table 2. Chemical composition of *Ximenia americana* from the semiarid region of Brazil based on fresh matter.

Variable	Seed	Pulp	
		Immature	Mature
Moisture (%)	8.07 ± 3.15[b]	65.99 ± 2.01[a]	64.91 ± 2.65[a]
Total soluble solids (°Brix)	17.95 ± 2.93[b]	26.89 ± 1.62[a]	26.22 ± 1.84[a]
Total soluble sugars (%)	3.66 ± 0.83[c]	9.49 ± 0.66[b]	10.64 ± 1.01[a]
Reducing sugars (%)	2.74 ± 0.60[b]	8.71 ± 0.86[a]	9.60 ± 1.57[a]
Starch (%)	11.00 ± 2.51[a]	5.70 ± 1.59[b]	5.17 ± 0.59[b]
Titratable acidity (mEq H_3O^+/100 g)	12.92 ± 2.15[c]	75.39 ± 4.72[a]	65.33 ± 7.39[b]
pH	4.16 ± 0.31[a]	3.03 ± 0.05[b]	2.96 ± 0.12[b]
Protein (%)	8.99 ± 0.57[a]	5.50 ± 0.34[b]	5.91 ± 1.08[b]
Lipid (%)	45.70 ± 4.40[a]	23.33 ± 2.37[b]	22.85 ± 3.25[b]
Ashes (%)	1.31 ± 0.11[b]	3.51 ± 0.45[a]	3.65 ± 0.83[a]

The same letters in the same row indicate no significant difference at a level by the Tukey test at 5% probability. Data expressed as mean ± standard deviation.

between pulps and seeds (Table 2). However, between maturity stages, mature pulp presented signficantly higher soluble sugar content while immature pulp presented signficantly higher titratable acidity. The pulp of the wild plum showed little variation in humidity values during maturation, 65.99% for immature and 64.91% for mature fruit, while the seed presented 8.07% of humidity (Table 2); these values agree with those reported for pulps from native Brazilian pulps; 37.7 to 90.2% (Gonçalves et al., 2010). The high soluble solids content (26 °Brix) observed for wild plum ranges among the recommended values for fruit processing. This almost surely certifies a more natural taste as greater contents of these constituents implies a reduced sugar addition, less time to evaporate water, lower energy consumption and higher product yield, resulting in a more economical process (Pereira et al., 2012). Mora et al. (2009) observed lower soluble solids contents (10.9 to 17%), for wild plums from Mexico.

The total soluble sugars and reducing sugars content were three times higher in pulp than in seed (3.6 and 2.7%, respectively), whereas for starch content, seeds (11%) had twice the amount found for pulp (Table 2). These parameters varied as maturation of *X. americana* progressed and levels of total sugars, reducing sugars and starch were similar to those reported for banana (Oliveira et al., 2013; Ribeiro et al., 2012), considered a rich source of carbohydrates. However, wild plum seeds presented lower levels of carbohydrates than seeds from other wild species as chicken lard (18.41%, *Swartzia langsdorfii* Radlk.) and 'cagaita' (17.84%, *Eugenia dysenterica* DC.) (Roesler et al., 2007).

Both pulp and seeds of *X. americana* present high titratable acidity, 65 and 12 mEq H_3O^+/100 g, and low pH, 2.9 and 4.1, respectively (Table 2). These results indicate that *X. americana* pulp is acidic. These are desirable characteristics for the processing industry as acidity contributes to an enhanced flavor, which promotes a high dilution factor in the formulation of juices leading to a greater yield while low pH dismisses any acidification during processing. Silva et al. (2008) also reported a pH value of 2.6 for pulp of mature wild plum and similar results to those here presented (pH 4.1) were found for seeds of ‘cagaita’ (pH 4.3) which were lower than those of seeds from chicken lard (pH 6.5), ‘araticum’ (pH 5.7, *Annona crassiflora* Martius) and ‘lobeira’ (pH 5.7, *Solanum lycocarpum* A. St.-Hil.) (Roesler et al, 2007).

The protein content was high in both seeds (8.9%) and pulp (5%) (Table 2), therefore wild plums represent an important source of protein when compared to other tropical fruit as yellow guava (4.24%, *Psidium cattleyanum* Sabine), ‘guabiroba’ (5.53%, *Campomanesia xanthocarpa* O. Berg) and ‘mandacaru’ (4.05%, *Cereus hildmannianus* K. Schum.) (Pereira et al., 2012; Pereira et al., 2013). Wild plum seeds present higher protein content than seeds of ‘banha’ (2.7%) and ‘cagaita’ (4.42%) (Roesler et al., 2007), ‘pequi’ almond (25.27%, *Caryocar brasiliense* Camb.) and in brown (19.1%) and gold flax seeds (21.6%) (Barroso et al., 2014; Lima et al., 2007).

X. americana seed stands out for the lipid content (45.7%), twice that of pulp (Table 2). It is considered high when compared to seeds from pequi (18%, *Caryocar brasiliense* Camb.), tucumã (19%, *Astrocaryum vulgare*) and avocado (8.4%, *Persea americana* Mill), as well as many other traditional and non-traditional fruit (Table 3). However, Saeed and Bashier (2010) reported lipid content values greater than 51% for wild plum seeds from Western Sudan. Ashes content of mature wild plum pulp was 3.65 and 1.31% for seed (Table 2), these were higher than found in pulp (0.93%), seed (0.93%) and exocarp (1.05%) of noni (*Morinda citrifolia* Linn.) (Costa et al., 2013), although lower than in cashew nut (2.6%, *Anacardium occidentale* L.) and raw nut (2.1%, *Carya illinoinensis* K. Koch.) (Taco, 2011).

X. americana pulp presented outstanding results when compared to other traditionally and non-traditionally marketed fruit (Table 3), suggesting a great exploitation potential esspecially, regarding their soluble solids, acidity, ashes, proteins and lipids contents in comparison to other native exotic fruit from semiarid Brazil as mandacaru/cardeiro (*Cereus jamacaru* DC); batinga (*Eugenia* sp); xique-xique (*Pilosocereus gounellei* Byles and G.D. Rowley); facheiro (*Pilosocereus pachycladus* F. Ritter); pirim (*Psidium schenckianum* Kiaersk); quixaba (*Sideroxylon obtusifolium* T.D. Penn); cumbeba (*Tacinga inamoena* N.P. Taylor and Stuppy.) and juá (*Ziziphus joazeiro* Mart) (Nascimento et al., 2011).

Bioactive compounds and total antioxidant activity

There was a significant difference among pulps and seeds regarding the bioactive compounds contents which were mostly higher in immature fruit pulp (Table 4). However, mature fruit pulp showed higher total vitamin C content of 187.98 mg/100 g, than immature pulp or seed. However, even higher total vitamin C levels (251.21 mg/100 g), were observed in preliminary studies with wild plums developed by our group (Silva et al., 2008). Thereby, wild plum represents a good source of vitamin C as its content is four times greater than recommended for daily intake of children and adults (45 mg). This is even more expressive when compared to other fruit listed on Table 3, as orange (73.3 mg/100 g, *Citrus sinensis*), tangerine (112 mg/100 g, *Citrus reticulata*) and açai (84 mg/100 g) (Rufino et al., 2010; Taco, 2011).

Immature *X. americana* pulp showed higher contents of total carotenoids, yellow flavonoids and anthocyanins than seeds or mature fruit (Table 4). Carotenoids are antioxidants as well as precursors of important vitamin A and *X. Americana* pulp presented higher contents than cashew apple (0.4 mg/100 g), ‘camu camu’ (0.4 mg/100 g), carnaúba (0.6 mg/100 mg, *Copernicia prunifera*), jaboticaba (0.32 mg/100 g, *Myrciaria cauliflora*), jambolan (0.51 mg/100 g, *Myrciaria cauliflora*), mangaba (0.3 mg/100 g, *Hancornia speciosa*) and myrtle (0.5 mg/100 g, *Blepharocalyx salicifolius*) (Rufino et al., 2010). The content found for *X. americana* seeds (0.59 mg/100 g) was higher than found for ‘pequi’ almond (0.295 mg/100 g) (Lima et al., 2007).

Yellow flavonoid contents of immature *X. americana* pulp were highest, followed by mature pulp (38.29 mg/100 g) and seeds (15.26 mg/100 g). It was also higher when compared to wild plum pulp from Burkina Faso (30 mg/100 g) (Lamien-Meda et al., 2008), acerola and camu-camu (Table 3). Total anthocyanin concentration was statistically higher in immature pulp (4.36 mg/100 g) followed by mature pulp (2.8 mg/100 g) and seeds (1.79 mg/100 g) and also, higher than reported for ‘mangaba’ (0.4 mg/100 g), murici (0.5 mg/100 g, *Byrsonima dealbata*), uvaia (1.13 mg/100 g, *Eugenia pyriformis*) and bacuri (0.3 mg/100 g, *Platonia insignis*) (Rufino et al., 2010). However, *X. americana* seeds contained less anthocyanins than nuts (18.02 mg/100 g), pistachio (6.06 mg/100 g), hazelnut (6.71 mg/100 g) and kernels (2.46 mg/100 g) (Bolling et al., 2011).

The content of total extractable polyphenols was statistically higher in immature pulp (4025 mg/100 g), followed by mature pulp (3002.08 mg/100 g) and seeds (2245.69 mg/100 g) (Table 4). According to Vasco et al. (2008), *X. americana* may be classified as a good source of phenolics as their contents were greater than 500 mg GAE/100 g. The phenolic content of wild plums reported here was higher than reported by Mora et al. (2009) for wild plums from Mexico (2960 mg GAE/100 g) and by Lamien Meda et al. (2008) for wild plums from Africa (2086.67 mg GAE/100 g). It was also higher than reported for blackberry (2167 mg GAE/100 g), bacuri (23.8 mg GAE/100 g) (Rufino et al., 2010; Vasco et al., 2008) and for pulp of other important fruit species (Table 3). These results indicated that wild plums are relevant sources of polyphenols, including its seeds with values

Table 3. Chemical composition and antioxidant activity of traditional and non-traditionally marketed fruit pulp.

Fruit	Moisture (%)	Protein (%)	Lipid (%)	Total Vitamin C (mg/100g)	Total Carotenoid (mg/100 g)	Total Anthocyanin (mg/100 g)	Yellow flavonoids (mg/100 g)	Total Polyphenol (mg/100 g)	DPPH EC50 (g/g)	ABTS (µmol Trolox/g)	Reference
Traditional											
Banana *Musa* spp.	77.7	1.2	0.1	-	-	-	-	-	-	48.3	TACO, 2011 Leong and Shui (2002)
Mango *Mangifera indica*	75 - 84	-	19 - 20	-	-	-	544.9	600.0	-	12.9 3.1	Kuskoski et al. (2006) Vasco et al. (2008)
Papaya *Carica papaya*	88.6	0.5	0.1	82.2	-	0.69	-	53.2	2.24	7.6	Almeida et al. (2011) Taco, (2011)
Acerola *M. emarginata*	91.0	0.9	0.2	1357.0	1.4	18.9	9.6	1063.0	670.0	96.6	Rufino et al. (2010) Taco 2011
Cashew Apple *A.occidentale*	86.9	1.0	0.3	190.0	0.4	9.5	63.8	830.0	906.0	79.4	Rufino et al. (2010) Taco 2011
Non-traditional											
Camu-camu *Myrciaria dubia*	89.8			1882.0	0.4	42.2	20.1	1176.0	478.0	153.0	Rufino et al. (2010)
Araticum-do-mato	78.6	-	-	32.0	-	-	-	531.7	15946.5	3.85	Pereira et al. (2013)
Yellow Guava *P. cattleyanum*	83.3	-	-	30.0	-	-	-	3713.2	389.7	242.30	Pereira et al. (2012)
Gabiroba *C. adamantium*	80.9	1.06	0.55	-	-	-	-	1.222.6	-	107.96	Alves et al. (2013)
Marolo *Annona crassiflora*	80.2	0.92	1.84	59.1	0.57	-	-	739.4	-	131.58	Souza et al. (2012)

higher than sprocket (206 mg/100 g) and nut (1602 mg/100 g) (Bolling et al., 2011).

According to both DPPH and ABTS methods, the total antioxidant activity of *X. americana* is high, although by DPPH method, there was no significant difference among treatments and by ABTS method, seeds had higher the total antioxidant activity (Table 4). Seeds are important sources of natural antioxidants and often have greater antioxidant activity than edible fruit portion itself (Guo et al., 2003; Oliveira et al., 2009; Morais et al., 2013). However, total antioxidant activity of wild plums was high compared to other fruit species (Table 3) and therefore, can be recommended for both fresh consumption and for uses in pharmaceutical, cosmetic and nutritional industries due to benefitial property of free radical neutralization, thereby reducing the inicidence of degenerative diseases. Lamien-Meda et al. (2008) reported that wild plum pulp from Burkina Faso also present high antioxidant capacity.

Table 4. Bioactive compounds and antioxidant activity of *Ximenia americana* from the semiarid region of Brazil based on fresh matter.

Variable	Seeds	Pulp	
		Immature	Mature
Total vitamin C (mg/100 g)	72.23 ± 6.99[c]	170.30 ± 16.01[b]	187.98 ± 10.51[a]
Total carotenoids (mg/100 g)	0.59 ± 0.09[b]	0.99 ± 0.12[a]	0.88 ± 0.09[a]
Yellow flavonoids (mg/100 g)	15.26 ± 2.69[c]	45.69 ± 4.81[a]	38.29 ± 7.33[b]
Total anthocyanins (mg/100 g)	1.79 ± 0.36[b]	4.36 ± 1.44[a]	2.81 ± 0.18[b]
Total polyphenols (mg/100 g)	2245.69 ± 287.58[c]	4025.86 ± 551.64[a]	3002.08 ± 790.04[b]
DPPH (EC_{50}) (g /g DPPH)*	335.00 ± 15.86[a]	293.89 ± 61.55[a]	325.85 ± 32.19[a]
ABTS (µmol Trolox/g)	304.48 ± 48.51[a]	158.57 ± 32.70[b]	187.57 ± 47.05[b]

The same letters in the same row indicate no significant difference at a level by the Tukey test at 5% probability. Data expressed as mean ± standard deviation.*Concentration of antioxidant required to reduce the original amount of free radicals by 50%.

Table 5. Correlation between bioactive compounds and total antioxidant activity from wild plums from the semiarid region of Brazil.

	Flavonoids	Anthocyanins	Polyphenols	Carotenoids	Vitamin C	DPPH
Pulp						
Anthocyanins	0.5927*					
Polyphenols	0.2125	0.3627				
Carotenoids	-0.3980*	0.0675	0.2754			
Vitamin C	-0.3496	0.0533	0.4414*	0.0089		
DPPH	-0.2055	-0.3067	-0.7295*	-0.2641	-0.4777*	-
ABTS	0.1774	0.3123	0.8491*	0.1856	0.4165*	0.7725*
Seeds						
Anthocyanins	0.4371					
Polyphenols	0.2439	-0.2772				
Carotenoids	0.3036	0.6168*	-0.0104			
Vitamin C	0.0951	-0.4204	0.5016	-0.0810		
DPPH	0.1422	0.6461*	-0.8090*	0.4095	-0.5096	
ABTS	-0.2772	-0.5224	0.4870	-0.3591	0.2129	0.5956*

*Significant at $p < 0.01$.

According to the Pearson's correlation analysis between bioactive compounds and total antioxidant activity for wild plums (Table 5), there were significant interaction between total antioxidant activity and polyphenolic and vitamin C contents for mature pulp. For the DPPH method, correlation was negative since this method evaluates the amount of sample necessary to neutralize DPPH radical, the smaller values represent a higher antioxidant activity (inversely proportional to the antioxidant activity). Therefore, polyphenols and vitamin C are mainly responsible for the high antioxidant activity of wild plum pulp. However, for wild plum seeds, antioxidant activity was significantly correlated only to total antioxidant activity determined by DPPH method. Alves et al. (2013) also observed that the total phenolic content was positively correlated with the antioxidant activity of gabirobeira (*Camponesia adamantium*).

Mineral composition

There was a significant difference in sodium, potassium, magnesium, calcium and iron contents were generally higher in *X. americana* pulp (Table 6). Sodium levels were three times higher in pulp than seeds and considerably higher than reported for mature açai pulp (6.8 mg/100 g, *Euterpe oleracea* Mart.) (Gordon et al., 2012). Pulp potassium content (101.5 mg/100 g) was twice that of seed, representing 50% of the average levels reported for banana (263 mg/100 g) (Taco, 2011),

Table 6. Mineral content of wild plums from the semiarid region of Brazil.

Minerals (mg/100 g)*	Seeds	Pulp	
		Immature	Mature
Sodium	11.22 ± 1.56[b]	29.16 ± 5.04[a]	36.22 ± 12.32[a]
Potassium	56.90 ± 2.34[b]	110.12 ± 11.62[a]	101.56 ± 19.78[a]
Phosphorus	2367.77 ± 51.67[a]	2484.24 ± 223.84[a]	2425.22 ± 285.16[a]
Magnesium	0.95 ± 0.07[b]	1.23 ± 0.18[a]	1.20 ± 0.24[a]
Calcium	2.40 ± 0.09[b]	4.41 ± 0.29[a]	4.14 ± 0.51[a]
Copper	0.025 ± 0.00[a]	0.028 ± 0.02[a]	0.030 ± 0.02[a]
Zinc	0.093 ± 0.01[a]	0.110 ± 0.02[a]	0.131 ± 0.06[a]
Iron	0.21 ± 0.06[b]	0.347 ± 0.06[a]	0.367 ± 0.16[a]
Manganese	1.51 ± 0.30[a]	1.334 ± 0.27[a]	1.297 ± 0.26[a]

The same letters in the same row indicate no significant difference at a level by the Tukey test at 5% probability. Data expressed as mean ± standard deviation. *Expressed in mg/100 g dry matter.

which is well known as a good potassium source. Lime orange (130 mg/100 g, *Citrus sinensis* (L.) Osbeck) and mango (138 mg/100 g, *Mangifera indica* L. cv. Tommy Atkins) have potassium levels similar to those found for *X. americana* (Taco, 2011).

Phosphorus content present in the seed (2367 mg/100 g) and pulp (~2400 mg/100 g) of *X. americana* were higher than acerola (*Malpighia glabra* L.), pineapple (*Arabic comosus* (L.) Merril), cocoa (*Theobroma arábi* L.), guava (*Psidium guajava* L.), soursop (*Annona muricata* L.), Brazil nut (*Bertholletia excelsa* HBK), sesame seed (*Sesamum indicum* L.), flax (*Linum usitatissimum* L.) and walnut (*Carya illinoinensis* K. Koch.) (Taco, 2011). Magnesium were lower than reported for marolo pulp (26.28 mg/100 g, *Annona crassiflora* Mart.), genipap (8.17 mg/100 g, *Genipa americana* L.), murici (10.14 mg/100 g, *Byrsonima crassifolia* L. Rich), soursop (10.61 mg/100 g, *Annona muricata* L.) and sweet passion fruit (19.82 mg/100 g, *Passiflora alata* Dryand) (Souza et al., 2012).

Pulp had higher calcium levels (~4.41 mg/100 g) than seeds (2.4 mg/100 g) and could be compared to murici pulp (5.50 mg/100 g, *Byrsonima crassifolia* L. Rich) and sweet passion fruit (4.76 mg/100 g, *Passiflora alata* Dryand) (Souza et al., 2012). Although, it was lower than acerola (13 mg/100 g), pineapple (22 mg/100 g), banana (8 mg/100 g, *Musa acuminata* Colla x *Musa balbisiana* Colla, AAB cv. Prata) and cocoa (12 mg/100 g, *Theobroma arabi* L.) (Taco, 2011).

There was no significant difference for copper, zinc and magnesium levels between pulps and seed (Table 6). The copper content present in the seed and pulp (>0.024 mg/100 g) of wild plum was higher than recommended for daily intake of a human adult (Brasil, 2005). The zinc content of the pulp, ~0.1 mg/100 g, was similar to those reported for different banana cultivars (0.1 - 0.3 mg/ 100 g) (Taco, 2011). Manganese content was similar between wild plum seeds and pulp (~1.3 mg/100 g), and such concentrations meet 75% of the recommended daily intake for adults (2.5 mg/day) (Brasil, 2005). These values were higher than found in acerola (0.07 mg/100 g), banana cv. Prata (0.42 mg/100 g), cocoa (0.04 mg/100 g), cashew (0.12 mg/100 g), guava (0.08 mg/100 g), soursop (0.08 mg/100 g) and papaya (0.01 mg/100 g) (Taco, 2011). Iron levels were higher in pulp and also considered high when compared to acerola (0.2 mg/100 g), cashew apple (0.2 mg/100 g), guava (0.2 mg/100 g), soursop (0.2 mg/100 g) and papaya (0.20 mg/100 g) (Taco, 2011).

Conclusions

The *X. americana* grown in Brazilian semiarid region presents a great potential to further commercial exploitation. The pulp, aside its maturation stage contains high levels of lipids, proteins, sugars, starch, titratable acidity, vitamin C, yellow flavonoids, polyphenols and antioxidant activity. The seed also presents high levels of lipid, protein, starch, total extractable polyphenols and antioxidant activity. Imature pulp stands out for acidity, polyphenol, flavonoid and anthcyanin levels, while mature fruit pulp has higher yield, sugar and vitamin C levels. Seeds have higher starch, protein and lipid levels. The antioxidant activity found for wild plum pulp could be attributed to polyphenol and vitamin C contents; meanwhile, the antioxidant activity of seeds was dependent only on polyphenolic content. Pulp had higher Na, K, Mg, Ca and Fe levels, however, both seed and pulp fractions have substantial contents of P, K, Cu and Mn. This work indicate promising perspectives for the exploitation of this fruit and dissemination of data on its constituents is critical and enables it to be introduced in production systems and consequently, marketed.

Conflict of interests

The authors did not declare any conflict of interest.

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