Physicochemical, nutritional and health-related component characterization of the underutilized Mexican serviceberry fruit [*Malacomeles denticulata* (Kunth) G. N. Jones]

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Physicochemical, nutritional and health-related component characterization of the underutilized Mexican serviceberry fruit [*Malacomeles denticulata* (Kunth) G. N. Jones].

Abstract – Introduction. The nutritional and functional qualities of wild and cultivated Mexican serviceberry have not yet been reported. This species could have similar potential for commercialization to that of Saskatoon berry (*Amelanchier alnifolia* Nutt.). **Materials and methods**. Wild and cultivated fruits at two maturity stages were assessed for CIE Lab color, fruit size, titratable acidity and total soluble solids. Also, chemical composition and mineral contents were determined. In addition, vitamin C and simple phenols were assessed. Total soluble phenols, condensed tannins and anthocyanins as well as Trolox antioxidant activity and oxygen radical antioxidant activity were determined. **Results**. Fruit size, titratable acidity, total soluble solids, iron and simple phenols were higher in fruits of cultivated plants than in those of wild plants. Total fiber, calcium, vitamin C, total soluble phenols and condensed tannins were higher in wild fruits. Wild and cultivated serviceberry showed higher Trolox antioxidant activity compared with oxygen radical antioxidant activity. Caffeic, chlorogenic, coumaric and syringic acids and rutin were the predominant simple phenolics; they comprised from 59.3% (cultivated overripe fruit) to 76.9% (wild ripe fruit) of the sum of simple phenolics. The antioxidant activity of wild and cultivated fruit (258.3–699.2 mmol·kg^{-1}, fw) is up to 3.8 times higher compared with those of fruits commonly consumed. **Conclusion**. Contents of antioxidant compounds and the outstanding antioxidant activities of wild and cultivated Mexican serviceberry make this species a natural resource that could contribute to health.

Mexico / *Malacomeles denticulata* / amelanchier / fruits / phenolic acids / antioxidants

Caractérisation des composés physico-chimiques, nutritionnels et liés à la santé du fruit de l'amélanchier mexicain sous-utilisé [*Malacomeles denticulata* (Kunth) G.N. Jones].

Résumé – Introduction. Les qualités nutritionnelles et fonctionnelles des amélanchiers mexicains sauvages et cultivés ne sont pas encore connues. Cette espèce pourrait avoir le même potentiel de commercialisation que celle de l'amélanchier *alnifolia*. **Matériel et méthodes**. Les fruits de plants sauvages et cultivés ont été évalués à deux stades de maturité pour les paramètres de coloration CIE Lab, la taille des fruits, l'acidité titrable et les solides totaux solubles. En outre, la composition chimique et la teneur en minéraux ont été déterminées. Par ailleurs, les teneurs en vitamine C et en phénols simples ont été évaluées. Les phénols solubles totaux, tanins condensés, anthocyanines, ainsi que l'activité antioxydante Trolox et l'activité antioxydante des radicaux d'oxygène ont été déterminés. **Résultats**. La taille des fruits, l'acidité titrable, les solides solubles totaux, le fer et la teneur en phénols simples ont été plus élevés dans les fruits de plants cultivés que dans les ceux de plants sauvages. La teneur totale en fibres, calcium, vitamine C, phénols solubles totaux et tannins condensés a été plus élevée dans les fruits sauvages. Les amélanchiers sauvages et cultivés ont montré une activité antioxydante Trolox supérieure à celle de l'activité antioxydante du radical de l'oxygène. Les acides caféique, chlorogénique, coumarique et syringique, ainsi que la rutine ont été les composés phénoliques simples prédominants ; ils représentent de 59,3 % (fruits sur-mûrs cultivés) à 76,9 % (fruits mûrs sauvages) de la somme des composés phénoliques simples. L'activité antioxydante des fruits sauvages et cultivés (258,3–699,2 mmol·kg^{-1} de poids frais) a été jusqu'à 3,8 fois plus élevée que celle des fruits de consommation courante. **Conclusion**. La teneur en composés antioxydants et les activités antioxydantes remarquables de l'amélanchier mexicain sauvage et cultivé font de cette espèce une ressource naturelle qui pourrait être bénéfique à la santé.

Mexique / *Malacomeles denticulata* / amélanchier / fruits / acide phénolique / antioxydant

1. Introduction

Malacomeles is a genus that belongs to the family Rosaceae, subtribe Pyrinae (formerly Maloideae subfamily). Five species of *Malacomeles* have been described, distributed in the United States (Texas), Mexico, Guatemala, Costa Rica and Honduras [1]. Of those five species, *Malacomeles denticulata* (formerly *Amalenchier denticulata*) is the most widely distributed in Mexico. Wild fruit of *M. denticulata* has been consumed by animals and humans from pre-Columbian times and is known as southern false serviceberry and Mexican serviceberry. The fruit of the wild Mexican serviceberry is globular in shape and dark pink in color when unripe and light pink when mature (*figure 1*). Wild ripe fruits average 6.5 mm equatorial length and 8.0 mm polar length. The peel is thin, and the flesh, which has a glowing white color, has a gel-like structure. The fruit contains one or two little seeds (2–3 mm) [2]. Criteria for harvest are based on the experience of indigenous collectors. It is a common practice to collect wild light pink (ripe) and light brown fruit (overripe). People consume the ripe fruit fresh or use it to make marmalade; fruit and marmalade are commercialized at local markets known as "tinaguis".

Figure 1.
Fruits of Mexican serviceberry (*Malacomeles denticulate*).

Serviceberry is mainly distributed in central Mexico in the Transmexican Volcanic Axis biogeographic province in the Mexican states of Guanajuato, Queretaro, Hidalgo, Puebla, Tlaxcala and State of Mexico, and also in the Sierra Madre del Sur biogeographic province in Oaxaca [3]. The areas of production of serviceberry have been identified and assessment of their production potential is in progress. The preliminary data is promising. Also, interest in serviceberry is raised because it is tolerant to several environmental conditions such as frost, drought, clay soil conditions and poor drainage [4]. However, given its vegetative compatibility with apple, our group has used rootstock of this species in order to introduce serviceberry to agricultural soils. On the other hand, serviceberry shows an advantage compared with other Rosaceae fruits: it does not have a hard endocarp, making it more attractive for processing in juices, syrups and jams.

A genus closely related to *Malacomeles* is *Amalenchier*, as was reported recently [5]. The species of the genus *Amalenchier* (Rosaceae, subtribe Ryrinae) that attracted interest for domestication was Saskatoon berry (*A. alnifolia* Nutt.), formerly called serviceberry. As a result, Saskatoon berry is currently exploited in many parts of the world for its suitability for various food products and due to its high content of nutrients and bioactive compounds [6, 7]. Hopefully, Mexican serviceberry fruit could have the opportunity for commercial exploitation similar to Saskatoon berry in the near future. In order to introduce the species, five years ago we grew wild Mexican serviceberry shrubs under cultivated conditions. In spite of its long history of consumption, the nutritional and functional characteristics of Mexican serviceberry have not been documented.

Evidence continues to emerge suggesting that antioxidant-rich, commonly consumed fruits and vegetables are beneficial to health. Besides antioxidant capacity, fruits and vegetables show other functional properties such as anti-proliferative, anti-carcinogenic, anti-aging and anti-inflammatory activities. These functional properties have a close relationship with the prevention of chronic diseases such as cancer, diabetes and cardiovascular diseases. The beneficial effects are the result of the biological activity of certain compounds such as flavanols, flavonols, flavanes, anthocyanidins, vitamin C and other non-nutrients [8], which justify the identification and quantification of compounds of interest in fruits as well as their biological activities.

The aim of this work was to evaluate the potential of wild and cultivated Mexican serviceberry as a functional food by characterizing the physicochemical characteristics, nutritional composition, vitamin C, phenolics and antioxidant capacity (TEAC and ORAC). In addition, the characterization and quantification of phenolic acids, flavanols and flavonols by high-performance liquid chromatography-diode array detection (HPLC-DAD) were carried out as well.

2. Materials and methods

2.1. Fruit samples

Wild and cultivated Mexican serviceberry fruit was harvested from shrubs grown in the mountain range (calcareous soils) and agricultural lands of Celaya, Guanajuato, Mexico. We ensured that the Mexican serviceberry shrubs selected to harvest the samples showed the botanical characteristics described by Turner [9] for this species. Cultivated shrubs were developed from wild seeds which were planted in 2006 in agricultural lands and subjected to controlled irrigation and fertilization. After five years of growing, the shrubs produced abundant fruit. During the production season, any particular shrub may bear fruits corresponding to unripe, ripe (light pink) and overripe (light brown) stages. Fruit were harvested in July 2011 from six different shrubs from each site, separating the fruit by color into two different bulks of fruit (ripe and overripe) for each shrub. The ripe and overripe fruit from the six shrubs were used for chemical analysis (n = 6). Immediately after harvest, samples were protected from light to avoid loss of antioxidant components. When the samples arrived at the laboratory, they were divided into two portions. One portion was used to determine the physicochemical parameters on the same day of harvest. The other portion was freeze-dried and stored at –20 °C until nutritional and functional analysis.

2.2. Physicochemical characteristics

Polar and equatorial length was measured by using a Vernier (LabQuest, Veaverton, OR, USA). The pH was measured with a pH meter (MI 255, Hanna Instruments, Woonsocket, RI, USA) and titratable acidity was determined by titration with 0.1 M NaOH [10]. Total soluble solids (°Brix) were determined using fruit juice with a hand refractometer (Pal-1, ATAGO, Tokyo, Japan). The surface color parameters "a^*" and "b^*" of fruits were determined using a Minolta CR-300 chromameter to calculate HUE [= arctang (b^*/a^*)] and chroma [= $(a^{*2} + b^{*2})^{1/2}$].

2.3. Nutritional composition

Nitrogen (ref. 960.52), ether extract (ref. 920.85) and ash (ref. 923.03) were measured by AOAC-approved methods [11]. Also, dietary fiber was determined by a standardized method [9]. The remaining percentage was considered to represent carbohydrates. The conversion factor for total protein was 6.25 (N × 6.25). Iron, zinc and calcium were determined after $HClO_4/HNO_3$ digestion in an inductively coupled plasma atomic emission spectroscopy analyzer (3000SC, Perkin Elmer, Wellesley, MA, USA).

2.4. Ascorbic and dehydroascorbic acids

Vitamin C was determined by high-performance liquid chromatography (HPLC) as reported by Corrales-Aguayo *et al.* [12]. Briefly, each fruit sample was extracted with 0.1 M citric acid and 0.05% ethylenediaminetetraacetic acid, (pH 2.35–2.40) in a shaker (Maxi Mix II M37615, Thermo Scientific, Dubuque, IA, USA) for 30 min. Each sample was thereafter centrifuged (5000 g, 10 min at 2 °C), and the supernatant was recovered and filtered (Sep-Pak C18 Vac 3-mL cartridge, Waters Corp., Milford, MA, USA), previously conditioned with 10 mL of HPLC-grade ethanol and then with 10 mL of HPLC-grade water. After discarding the first 5 mL, an aliquot of 3 mL was added to 1 mL (0.832 mg·mL^{-1}) of 1,2-phenylendiamine prepared in methanol/water (5:95, v/v). The sample was incubated for 35 min in the dark and filtered through a 0.45-µm nylon membrane. Aliquots of 40 µL were injected into a HP 1100 Series HPLC (Agilent Technologies, Inc., Santa Clara, CA, USA) equipped with a diode array detector (HPLC-DAD), dual wavelength UV-Vis detector, acquisition system (Agilent ChemStation Software Plus A.09.xx, Santa Clara, CA, USA), and a Zorbax octadecylsilane (ODS-C18) reverse-phase column. The mobile phase consisted of 5 mM hexadecyl-trimethylammonium bromide (cetrimide) and 50 mM KH_2PO_4 in methanol/water (1:99, v/v) at pH 4.6. The flow rate was 1.5 mL·min^{-1}. Ascorbic acid was monitored at 261 nm, while dehydroascorbic acid was monitored at 348 nm.

Calibration curves were prepared from standards and used for quantification.

2.5. Total soluble phenols

Each sample was extracted with methanol/water (30:70, v/v) for 10 min with a shaker (Maxi Mix II M37615, Thermo Scientific, Dubuque, IA, USA), in the dark. The supernatant identified as phenol extract was recovered and the total soluble phenols were determined using Folin-Ciocalteu reagent [13]. Absorbance was measured using a UV-Vis spectrophotometer (Jenway 6405, Staffordshire, UK) at 760 nm. Total soluble phenols were expressed as g of gallic acid Eq·kg^{-1} sample, fresh weight.

2.6. Condensed tannins

Fruit samples were extracted with methanol in capped, rotating test tubes for 20 min. Five milliliters of reagent A (1:1, v/v, of 1% vanillin in methanol fresh daily and 8% HCl in methanol) were added to 1-mL aliquots of sample supernatant. Five milliliters of 4% concentrated HCl in methanol were added to a second 1-mL aliquot (the blank); both were incubated for 20 min at 30 °C [14]. Samples were spectrophotometrically measured at 500 nm (Jenway 6405 UV–Vis, Staffordshire, UK). Condensed tannins were reported as g (+) catechin Eq·kg^{-1}, fresh weight after comparing with a (+) catechin standard curve.

2.7. Total anthocyanins

Fruit samples were extracted with acidified ethanol (ethanol/HCl, 1 N, 85:15, pH 1.0) for 45 min. The supernatant was added to acidified ethanol up to 50 mL. Absorbance (Jenway 6405 UV-Vis, Staffordshire, UK) was recorded at 535 nm. Total anthocyanins (TAN) were calculated and reported as grams cyanidin 3-glucoside equivalents fresh weight basis, as follows [15]: $TAN = (A/\varepsilon)(V/1000)\ (MW)\ (1/SW)\ (10^6)$, where: A = sample absorbance; ε = molar absorptivity of the cyanidin-3-glicoside (cm^{-1}·M^{-1}); V = total volume of anthocyanin extract; MW = molecular weight of cyanidin-3-glucoside (449 Da); SW = sample weight.

2.8. Simple phenols

The phenol extracts recovered for the analysis of phenols (see subsection total soluble phenols) were utilized to determine phenolic acids, flavanols and flavonols by HPLC. A 15 cm × 4.6 mm internal diameter, 5-µm particle size Zorbax octadecylsilane (ODS-C18) (ABC Instrumentación, Distrito Federal, México) reversed-phase column was utilized. Linear gradient elution was carried out by using solvent A (acetic acid/water, 2:98, v/v), and solvent B (acetic acid/acetonitrile/water, 2:30:68, v/v/v). During the analysis, the solvent gradient was programmed from 10% to 100% B in A, in 30 min, with a flow rate of 1.5 mL·min^{-1} [16]. The identification and quantification of the peaks were carried out from (1) the retention times, (2) the spectra derived from the DAD in comparison with those from authentic standards, and (3) by spiking with standards of the suspected compounds. Gallic, protocatechuic, 4-hydroxybenzoic, vanillic, chlorogenic, caffeic, syringic, coumaric, ferulic, benzoic and salicylic acids, as well as (+)-catechin, vanillin, epicatechin (EC) and epigallocatechin gallate (EGCg) were detected at 280 nm; meanwhile, ellagic acid, quercetin and rutin were detected at 360 nm. Simple phenols were reported as mg per kilogram, fresh weight.

2.9. Antioxidant activities

The ABTS (7 mM) radical cation (ABTS$^+$) solution was produced by reacting ABTS with 2.45 mM potassium persulfate and allowing the mixture to stand in the dark at room temperature for 12–16 h before use. The ABTS$^+$ radical was diluted with potassium phosphate-buffered saline to give an absorbance of about 0.700 ± 0.020 at 734 nm. To measure antioxidant capacity, ten µL of sample was mixed with 990 µL of radical solution. Absorbance was monitored at 734 nm for 6 min. The decrease in absorption at 734 nm, 6 min after addition of the sample, was used for calculating the TEAC value comparing with a standard curve of TROLOX [17]. Results were expressed in terms of mmol Trolox Eq·kg^{-1} of sample, fresh weight. The oxygen radical absorbance capacity assay (ORAC) of samples was

Table I.
Fruit size, pH, titratable acidity, total soluble solids, maturity index, Hue and Chroma of wild and cultivated Mexican serviceberry (*Malacomeles denticulate*).

Maturity stage	Fruit size polar × equatorial (mm)	pH	Titratable acidity (TA) (g malic acid Eq·kg^{-1} fw)	Total soluble solids (TSS) (g·kg^{-1} fw)	Maturity index [TSS/TA]	Hue (h)	Chroma (C*)
Wild							
Ripe	8.1 × 7.6 b	4.3 ± 0.0 b	5.5 ± 0.1 c	37.1 ± 1.4 c	6.75 ± 0.21 d	9.3 ± 0.3 d	27.9 ± 0.1 a
Overripe	5.3 × 5.1 d	4.5 ± 0.5 ab	14.8 ± 0.0 b	177.1 ± 5.2 a	11.97 ± 0.86 a	32.7 ± 1.5 b	13.3 ± 1.0 b
Cultivated							
Ripe	9.0 × 11.0 a	4.9 ± 0.0 a	5.8 ± 0.2 c	42.3 ± 1.2 b	7.29 ± 0.19 c	22.2 ± 0.7 c	28.5 ± 0.9 a
Overripe	7.6 × 6.2 c	5.0 ± 0.2 a	18.5 ± 0.5 a	186.7 ± 9.0 a	10.01 ± 0.12 b	37.7 ± 2.9 a	15.3 ± 1.1 b

Means in the same column with a common letter are not significantly different ($p < 0.05$).

also carried out [18]. The assay measures the ability of antioxidant compounds in test materials to inhibit the decline of fluorescein fluorescence that is induced by a peroxyl radical generator, AAPH. The final results (ORAC values) were calculated using the differences between blank and sample areas under the quenching curves of fluorescein, and were expressed as mmol Trolox Eq·kg^{-1} of sample, fresh weight.

2.10. Statistical analysis

All data were reported as means ± standard deviations (n = 6). Statistical analysis was performed using the JMP.5.0.1 software (a business unit of SAS, 1989–2003 SAS Institute Inc., NC, USA). Differences among means were tested for significance by ANOVA procedures and Tukey's test, using a level of significance of 0.05.

3. Results and discussion

3.1. Physicochemical characteristics

The size of wild Mexican serviceberry fruit was on average smaller compared with the size of cultivated fruit (*table I*). These results are in agreement with Stushnoff, who reported that cultivated Saskatoon berry showed up to 25% larger fruit size compared with that of wild fruit [19]. The equatorial diameter of domesticated Mexican serviceberry fruit (11.0 mm) is within the range reported for Saskatoon berry at maturity (10.8–13.9 mm) [20]. The pH of wild fruits was lower than the pH of cultivated fruits (*table I*). On the other hand, the pH of wild and cultivated Mexican serviceberry was higher compared with that of cultivated Saskatoon berry (3.65–4.17) [19]. The higher pH indicates that this fruit is a low-acid food. The titratable acidity of cultivated ripe fruit (5.8 g·kg^{-1}, fw) and overripe fruit (18.5 g·kg^{-1}, fw) was higher than that of wild fruit at the corresponding maturity stage (*table I*). However, wild and cultivated ripe fruit showed a similar concentration of titratable acidity compared with that of some cultivars of Saskatoon berry (3.12–6.31 g·kg^{-1}, fw) [20]. Similar titratable acidity content in serviceberry and Saskatoon berry means that both fruits contain similar organic acid contents. The total soluble solids of both wild (37.1 g·kg^{-1}, fw) and cultivated (42.3 g·kg^{-1}, fw) ripe fruit were lower compared with the total soluble solids of 16 Saskatoon cultivars (145.0-201.0 g·kg^{-1}, fw) [19, 21]. Only overripe wild and cultivated fruit showed similar total soluble solids (177.1 g·kg^{-1}, fw, and 186.7 g·kg^{-1}, fw, respectively) to the Parkill and Nelson Saskatoon cultivars [21]. Wild and cultivated ripe Mexican serviceberry would have a longer shelf life due to a lower [total soluble solids / titratable acidity] ratio [22, 23] compared with that of Saskatoon berry cultivars, that show on average 39.9 for the [total soluble solids / titratable acidity] ratio [21]. The low [total soluble solids / titratable acidity] ratio found in ripe fruit in this study was primarily due to the acidity of the fruit and was similar to those found for Saskatoon berry [24]. On the other hand, cultivation of Mexican serviceberry increased titratable acidity levels and total soluble solids in general compared with those of wild samples at all maturity stages (*table I*). The same effect was detected for hue and chroma characteristics.

3.2. Chemical composition

In general, there were no differences in protein content between wild and cultivated Mexican serviceberry at similar maturity stages (*table II*). The levels of protein contents reported here for ripe fruit were lower compared with those reported for Saskatoon berry (19.4 $g \cdot kg^{-1}$, fw) [23]; however, overripe fruit showed more than two-fold the protein content compared with ripe fruit, and higher protein content compared with that reported for Saskatoon berry. This is significant for rural areas where this type of food represents a significant part of the local populations' diet. Ripe and overripe cultivated Mexican serviceberry showed lower fiber contents compared with those of wild fruit (*table II*). However, the fiber contents in edible Mexican serviceberries reported here were higher than those reported by Mazza [25] for Saskatoon berry (38 $g \cdot kg^{-1}$, fw). The quantities of fiber detected in Mexican serviceberry fruit could make it a good source of dietary fiber. The beneficial effects of fibers in human health are widely known; dietary fiber, together with other functional phytochemicals, may contribute to the prevention of chronic diseases. According to the American Dietetic Association, a portion of 100 g of wild fruit could contribute 17% of the daily recommended intake of fiber (30 g); the same portion of overripe fruit could contribute 38%.

Cultivated fruit showed higher contents of iron and zinc compared with the iron and zinc contents of wild fruit (*table II*). On the contrary, the calcium content of cultivated fruit was in general 50% lower compared with that of wild fruit at all maturity stages. Such differences could be attributed to differences in soil Ca contents and other minerals between calcareous and agricultural soils where wild and cultivated Mexican serviceberry grows, respectively. No information concerning the soil content of Ca was available for our study. Iron contents of wild and cultivated overripe fruit were 2.2 times and 2.8 times higher, respectively, compared with that reported by Mazza [25] for Saskatoon berry (13.4 $g \cdot kg^{-1}$, fw). Similarly, the level of zinc of cultivated overripe fruit in our study was higher compared with the Zn level of Saskatoon berry (8.8 $g \cdot kg^{-1}$, fw) [26]. Therefore, the nutritional characteristics of Mexican serviceberry make this fruit a good source of fiber, Fe and Zn. This is important for children in rural regions who live mostly on diets high in plant-derived local foods (including Mexican serviceberry fruit), putting them at high risk of deficient growth and development. A 100-g portion of wild and cultivated Mexican serviceberry fruit could contribute from 10.3% to 21.7%, respectively, of the daily iron requirement.

3.3. Vitamin C

As L-dehydroascorbic acid shows biological activity and can easily be converted to L-ascorbic acid by humans, the sum of ascorbic acid and L-dehydroascorbic acid was regarded as vitamin C [12]. Wild overripe and cultivated ripe and overripe Mexican serviceberry did not show ascorbic acid (*table III*). On the contrary, the oxidized form of ascorbic acid, dehydroascorbic acid, was present at all maturity stages of wild and cultivated Mexican serviceberry, ranging from 0.582 $g \cdot kg^{-1}$ (wild overripe) to 1.071 $g \cdot kg^{-1}$ (wild ripe), being higher in wild fruits. The level of ascorbic acid in wild ripe Mexican serviceberry was 2.5 times higher than the content reported by Stuchnoff for Saskatoon berry (0.10 $g \cdot kg^{-1}$, fw) [19]. Similarly to Saskatoon berry [19], some samples of Mexican serviceberry fruit did not show ascorbic acid. When compared on a fresh weight basis, the vitamin C content of ripe and overripe Mexican serviceberry (0.582–1.320 $g \cdot kg^{-1}$, fw) turns out to be higher than in most common fruits such as plum (0.095 $g \cdot kg^{-1}$, fw), grape (0.108 $g \cdot kg^{-1}$, fw), apple (0.046 $g \cdot kg^{-1}$, fw), peach (0.010 $g \cdot kg^{-1}$, fw), banana

Table II.
Chemical composition (g·kg^{-1} fw) and mineral content (mg·kg^{-1} fw) of wild and cultivated Mexican serviceberry (*Malacomeles denticulate*).

Maturity stage	Protein	Fibre			Ether extract	Ash	Carbohydrates	Mineral		
		Soluble	Insoluble	Total				Fe	Zn	Ca
Wild										
Ripe	11.2 ± 0.4 b	4.2 ± 0.9 c	48.0 ± 0.4 c	52.2 d	8.1 ± 0.4 d	7.2 ± 0.4 c	149.3 d	15.5 ± 1.3 d	14.1 ± 0.5 b	3114 ± 90 c
Overripe	23.5 ± 2.5 a	14.8 ± 1.7 a	106.0 ± 1.7 a	120.8 a	23.4 ± 0.2 b	15.4 ± 0.3 b	434.4 a	28.8 ± 1.1 c	10.0 ± 0.3 d	9965 ± 82 a
Cultivated										
Ripe	10.9 ± 1.1 b	3.8 ± 0.4 c	43.7 ± 1.7 d	47.5 c	14.3 ± 1.4 c	6.9 ± 0.4 c	161.4 c	42.5 ± 0.9 a	12.1 ± 0.4 c	2510 ± 51 d
Overripe	26.5 ± 2.4 a	11.7 ± 1.1 b	99.4 ± 1.8 b	111.1 b	25.3 ± 0.2 a	16.7 ± 0.4 a	423.4 b	37.5 ± 1.9 b	15.3 ± 0.6 a	6848 ± 193 b

Means in the same column with a common letter are not significantly different ($p < 0.05$).

Table III.
Vitamin C and total soluble phenols, condensed tannins, and total anthocyanins of wild and cultivated Mexican serviceberry (*Malacomeles denticulate*).

Maturity stage	Vitamin C (g·kg^{-1} fw)			Total soluble phenols (g gallic acid Eq.·kg^{-1} fw)	Condensed tannins (g (+) catechin Eq·kg^{-1} fw)	Total anthocyanins (g cyanidin 3-glucoside Eq·kg^{-1} fw)
	Ascorbic acid	Dehydroascorbic acid	Total			
Wild						
Ripe	0.249 ± 0.007	1.071 ± 0.031 a	1.320 a	4.242 ± 0.380 c	1.436 ± 0.032 a	0.026 ± 0.001 c
Overripe	Not detected	0.582 ± 0.025 c	0.582 c	8.058 ± 0.150 a	1.373 ± 0.039 a	0.057 ± 0.006 a
Cultivated						
Ripe	Not detected	0.586 ± 0.010 c	0.586 c	3.831 ± 0.260 c	1.251 ± 0.035 b	0.046 ± 0.001 b
Overripe	Not detected	0.693 ± 0.025 b	0.693 b	5.844 ± 0.430 b	1.137 ± 0.041 c	0.063 ± 0.005 a

Means in the same column with a common letter are not significantly different ($p < 0.05$).

(0.087 g·kg^{-1}, fw), blackberry (0.21 g·kg^{-1}, fw) and blueberry (0.097 g·kg^{-1}, fw)[1]. The recommended daily intake of vitamin C for adults is 0.06 g per day and, therefore, a portion of 100 g of ripe and overripe Mexican serviceberry could contribute more than 100% of the recommended daily intake of vitamin C.

3.4. Phenolic compounds

Cultivated fruit showed lower total soluble phenols and condensed tannins compared with wild fruit (*table III*). For example, wild ripe and overripe fruit showed 9.7% and 27.5% higher total soluble phenols, respectively, when compared with cultivated overripe fruit. The total soluble phenols shown by overripe serviceberry, both wild and cultivated, were similar to those reported for Saskatoon berry (5.545–8.014 g·kg^{-1}, fw) [6]. Based on the total soluble phenol contents, wild ripe and overripe Mexican serviceberries are excellent total soluble phenol sources compared with commonly consumed fruits. For example, the total soluble phenol contents reported for strawberry, raspberry, red plum and grape (1.50–3.30 g·kg^{-1}, fw) [8] and blueberry (1.79 g·kg^{-1}, fw) [27] were significantly lower than the total soluble phenol contents reported here for Mexican serviceberry (3.831–8.058 g·kg^{-1}, fw). A high positive correlation between total soluble phenols and antioxidant capacity has been established [12, 27]; therefore, from a functional point of view, Mexican serviceberry is a very attractive fruit. On the other hand, the contents of condensed tannins in Mexican serviceberry are attractive given the reported relation with human health. Condensed tannins are reported to be anticarcinogenic and antimutagenic agents, which is attributed to their antioxidative property, which is important in protecting cellular oxidative damage [28]. Comparing the total anthocyanin levels detected in Saskatoon berry (0.251–1.79 g·kg^{-1}, fw) [25, 26] with those of wild and cultivated ripe and overripe fruit (0.026–0.063 g·kg^{-1}, fw), Mexican serviceberry is not a good source of anthocyanins. The lower total anthocyanin content of serviceberry mirrored the pink color showed by ripe and overripe fruit (*figure 1*).

[1] USDA National Nutrient Database for Standard Reference, Release 21, 2008, available from: http://www.ars.usda.gov/nutrientdata.

3.5. Simple phenols

The HPLC chromatograms of caffeic, coumaric and chlorogenic acids detected in wild ripe and cultivated ripe fruit show that coumaric acid was not detected in the cultivated sample (*figure 2*). Benzoic, caffeic, chlorogenic, coumaric, gallic, syringic and vanillic acids were identified together with the flavanols catechin, epicatechin and epigallocatechin gallate, and the flavonol rutin (*table IV*). Of these compounds, caffeic, chlorogenic, coumaric and syringic acids and rutin were found to be the predominant ones in wild and cultivated ripe and overripe fruit; they comprised in edible Mexican serviceberry from 59.3% (cultivated overripe fruit) to 76.9% (wild ripe fruit) of the sum of simple phenolics. Other peaks were detected, but they did not match any of the standards used in the present work. Given the Pyrinae nature of Mexican serviceberry, such peaks could be proanthocyanidins with different degrees of polymerization [29], 3-O-caffeoylquinic acid, cyanidins, unknown hydroxycinnamic acid or quercetin derivatives reported in Saskatoon berry or other simple phenolics [6, 30].

With the exception of rutin, the contents of all simple phenolics detected in cultivated ripe and overripe serviceberry were higher compared with those of edible wild fruit. The levels of chlorogenic acid detected in ripe and overripe Mexican serviceberry were lower compared with the chlorogenic acid levels reported for 16 Saskatoon berry cultivars (421.9–1297 mg·kg^{-1}, fw) [6]. Also, the sum of the flavanols catechin and epicatechin in Mexican serviceberry were up to ten-fold lower compared with those reported for Saskatoon berry (~1100–3000 mg·kg^{-1}, fw) [6]. Such differences could be attributed to the different methods utilized; Bakowska-Barczak and Kolodziejczyk utilized a more drastic methodology for flavanol

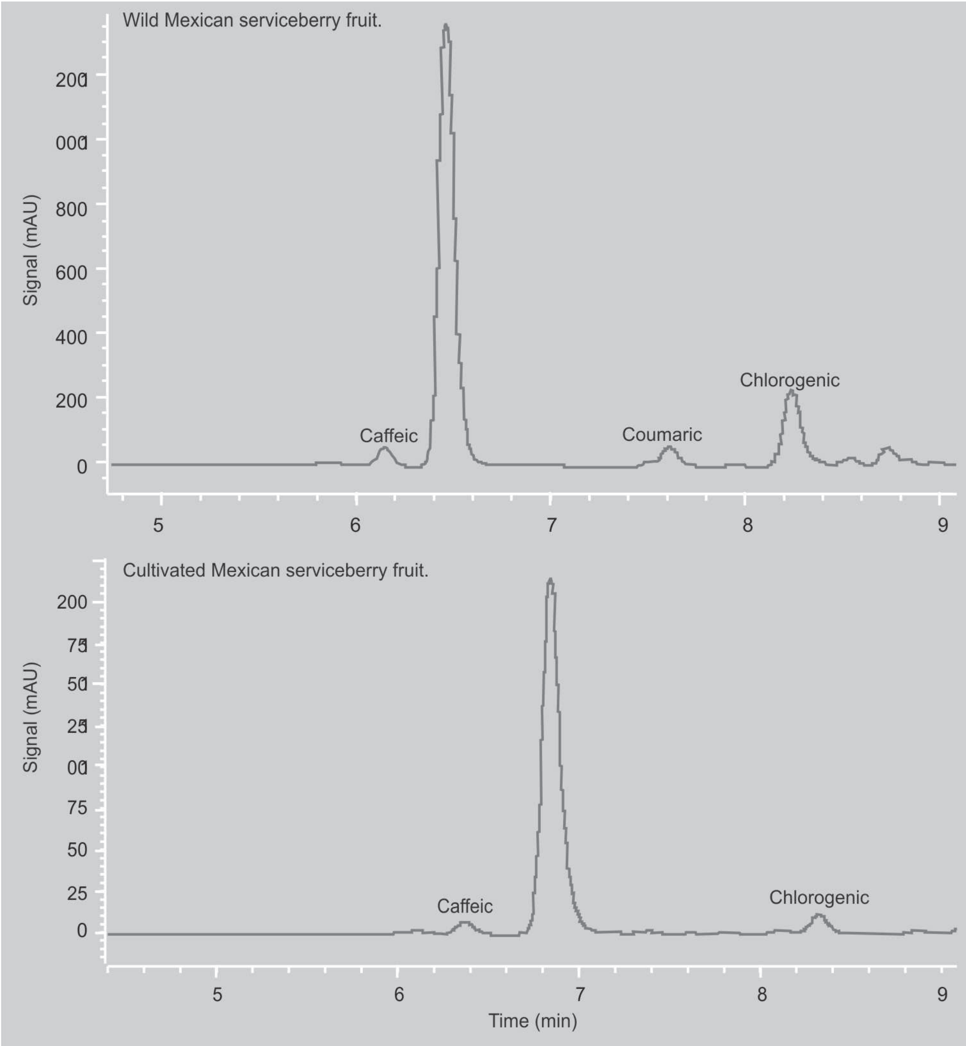

Figure 2.
HPLC chromatograms of phenolic acids detected in ripe wild and ripe cultivated Mexican serviceberry fruit (*Malacomeles denticulate*).

extraction [6]. On the other hand, Mexican serviceberry showed epigallocatechin gallate, which has not been reported for Saskatoon berry. Plants containing flavonoids are used to treat diabetes in Indian medicine; this compound is reported to have glucose-lowering effects [31] and represses hepatic glucose production [32] in animals. The presence of epigallocatechin gallate in Mexican serviceberry makes this fruit an excellent candidate to evaluate such an effect *in vivo*. Other simple phenolics detected in both Mexican serviceberry and Saskatoon berry are caffeic acid [33] and rutin (quercetin-3-O-rutinoside) [30]. However, Ozaga also detected quercetin 3-O-arabinoglucoside, galactoside, xylose and glucoside in Saskatoon berry, which we did not detect in Mexican serviceberry [30].

3.6. Antioxidant activities

For wild and cultivated fruits, higher TEAC values than ORAC values were observed in Mexican serviceberry (*figure 2*). This is not surprising, since flavanols have consistently shown lower antioxidant efficiency in terms of H-donating capacity than flavonols, when evaluated in *in vitro* systems [17, 34]. These results are consistent with the rutin concentration in wild samples, which represents one- to three-fold the concentration of the sum of the flavanols catechin, epicatechin

Table IV.
Phenolic acids, flavanols, and flavonol rutin ($mg \cdot kg^{-1}$ fw) of wild and cultivated Mexican serviceberry (*Malacomeles denticulate*).

Maturity stage	Phenolic acids							Flavanols			Flavonol	Total
	Benzoic	Caffeic	Chlorogenic	Coumaric	Gallic	Siringic	Vanillic	Catechin	Epicatechin	Epigallocatechin gallate	Rutin	
Wild												
Ripe	57.3 ± 3.5 c	231 ± 11 c	267 ± 10.1 d	161 ± 9.3	4.2 ± 0.2 d	185 ± 5.8 c	122 ± 8.7 b	34.5 ± 2.7 c	111 ± 16 c	17.8 ± 1.4 c	307 ± 16 a	1497.8 c
Overripe	43.9 ± 1.6 d	Not detected	407 ± 25.0 a	Not detected	9.6 ± 0.9 b	315 ± 15.4 b	95 ± 8.5 c	62.4 ± 2.0 a	117 ± 12 c	33.3 ± 6.2 b	318 ± 22 a	1401.2 d
Cultivated												
Ripe	79.8 ± 2.7 b	399 ± 54 b	382 ± 7.9 b	Not detected	8.4 ± 0.1 c	172 ± 4.3 d	141 ± 4.3 b	46.6 ± 0.5 b	205 ± 23 b	35.0 ± 1.5 b	251 ± 15 b	1719.8 b
Overripe	122 ± 31 a	529 ± 24 a	337 ± 7.4 c	Not detected	19.7 ± 1.2 a	551 ± 14.9 a	326 ± 45.1 a	59.3 ± 1.7 a	457 ± 93 a	193 ± 3.4 a	297 ± 19 a	2891.0 a

Means in the same column with a common letter are not significantly different ($p < 0.05$).

and epigallocatechin gallate. In wild samples, TEAC values were higher when compared with the TEAC values of cultivated ones. Also, a higher correlation was observed between rutin and TEAC (r = 0.99442, $p < 0.0001$). Not to be underestimated in the TEAC antioxidant activity is the contribution of the total soluble phenols (TSP) with the phenolic acids; however, little information is available on the contribution of individual phenolic compounds to antioxidant activities in berry crops. A significant correlation in wild and cultivated serviceberry was also observed between TEAC and TSP (r = 0.7347, $p > 0.05$; r = 0.9476, $p > 0.0001$, respectively), and dehydroascorbic acid (r = 0.8812, $p < 0.001$; r = 0.8592, $p < 0.005$, respectively). ORAC values showed a lower correlation with TSP of wild fruit (r = 0.7725, $p < 0.05$) and a higher correlation with TSP of cultivated serviceberry (r = 0.9016, $p < 0.0001$). Significant correlations were also detected between TEAC values and benzoic, caffeic, chlorogenic, gallic and syringic acid contents of wild and cultivated Mexican serviceberry. Meanwhile, ORAC showed a significant correlation with coumaric, caffeic and benzoic contents in cultivated fruit.

Comparing the TEAC values of strawberry (259.1 mmol·kg^{-1}, fw) and raspberry (184.6 mmol·kg^{-1}, fw) [8] with the TEAC values reported here for edible wild and cultivated Mexican serviceberry (258.3–699.2 mmol·kg^{-1}, fw) (*figure 2*), it is obvious that Mexican serviceberry is by far a better source of antioxidant compounds. However, when comparing the Mexican serviceberry TEAC levels reported here with those reported for Saskatoon berry (9260–14860 mmol Trolox·kg^{-1}) [35], Mexican serviceberry showed by far lower TEAC values assuming that the report for Saskatoon berry is on a fresh weight basis. To our best knowledge, there are no reports of ORAC activities in Saskatoon berry.

4. Conclusion

This is the first report on the nutritional and functional properties of Mexican serviceberry. There is a growing interest in discovery of new food choices that offer a proactive means of health maintenance. The results of this work provided a detailed assessment of the chemical characteristics and the potential of wild and cultivated edible Mexican serviceberry as a functional fruit consumed fresh. The contents of fiber, iron and vitamin C make Mexican serviceberry a good source of these components, which is important from a nutritional point of view. Besides, considerable amounts of simple phenolics such as caffeic, coumaric and syringic acids and the flavonol rutin are present in this fruit. Some of these simple phenolics, together with complex phenolics, are connected to intracellular antioxidant mechanisms and antioxidant acting enzymes, making serviceberry an alternative fruit which could contribute to the prevention of chronic diseases resulting from oxidative stress. Based on these results, it is recommended to evaluate the effect of Mexican serviceberry on diabetes or cancer in animal or cellular models.

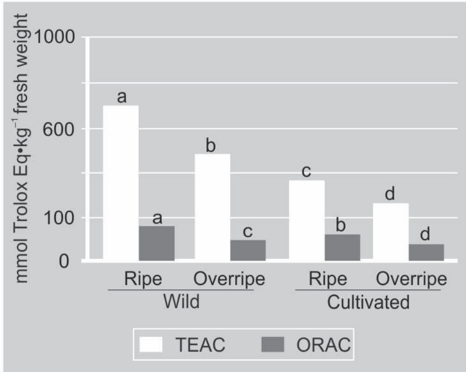

Figure 3.
Trolox equivalent antioxidant capacity (TEAC) and oxygen radical absorbance capacity (ORAC) of wild and cultivated ripe and overripe Mexican serviceberry. Bars with the same letter are not statistically different ($p < 0.05$, Tukey's test).

Differences in iron, zinc and simple phenolic contents in cultivated fruit could be associated with differences in cultural practices. In contrast, the higher contents of calcium, vitamin C, total soluble phenols and condensed tannins in wild serviceberry could be attributed to the water stress that the fruit suffers in the semiarid regions where it is produced. An opportunity for medium-scale production on marginal lands to serve this niche market is emerging; however, given the impact of cultivation practices on physicochemical parameters and some phytochemical constituents and the bioactive potency of serviceberries, it is critical that cultivated berry plots be designed to mimic, to the extent possible, conditions that are inherent in the wild.

Acknowledgment

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Caracterización fisicoquímica, nutricional y de los compuestos relacionados con la salud del fruto del membrillo Cimarrón [*Malacomeles denticulata* (Kunth) G. N. Jones].

Resumen – Introducción. Las características nutricionales y funcionales del membrillo cimarrón silvestre y cultivado no han sido reportadas. Esta especie puede llegar a tener un potencial para su comercialización similar si se compara con la mora Saskatoon (*Amelanchier alnifolia* Nutt.). **Materiales y métodos**. Se le determino a frutas silvestre y cultivada en dos estados de madures, el color CIE Lab, tamaño de fruto, acidez titulable y los sólidos solubles totales. También se determinó el análisis proximal y los minerales. Además, se analizaron la vitamina C y los compuestos fenólicos simples. Igualmente se determinaron los fenoles solubles totales, taninos condensados antocianinas y la actividad antioxidante Trolox y la actividad antioxidante del radical oxigeno. **Resultados**. El tamaño de fruto, acidez titulabe, solidos solubles totals, el hierro y los fenoles simples fueron mayores en fruto cultivado que en fruto silvestre. El contenido de fibra total, calcio, vitamina C, fenoles solubles totales y los taninos condensados fueron mayores en la fruta silvestre comparado con los de la fruta cultivada. Tanto la fruta silvestre como la cultivada mostraron mayor actividad antioxidante Trolox si se compara con la actividad antioxidante del radical oxigeno. Los ácidos cafeico, clorogénico, cumárico y siríngico, y la rutina fueron los fenoles simples predominantes; estos representan del 59,3 % (fruta sobre madura cultivada) al 76,9 % (fruta madura silvestre) de la suma total de los fenoles simples. La capacidad antioxidante de la fruta silvestre y cultivada (258,3–699,2 mmol·kg^{-1}, peso fresco) es 3,8 veces mayor si se compara con la de frutas que se consumen comúnmente. **Conclusión**. El contenido de compuestos antioxidantes así como la sobresaliente actividad antioxidante del fruto Silvestre y cultivado del membrillo Cimarrón hace de esta especie una fuente natural que puede contribuir en la salud.

México / *Malacomeles denticulata* / amelanchier / frutas / ácidos fenólicos / antioxidantes