Original Research Article

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Physicochemical characterization, bioactive compounds, and antioxidant activity of the wild berry *Ribes magellanicum*

José M Aguilera[1], M Carolina Moreno[1], Tamar Toledo[2] and Claudia Matamala[1]

Abstract

The Patagonian wild berry *Ribes magellanicum* has promising applications in food and nutrition due to its flavor and the presence of health-promoting bioactive compounds. Relevant chemical, physicochemical, and structural characteristics of the fruit for its utilization as food were investigated. The average moisture content was 79.3% while protein, lipids, sugars, and crude fiber amounted to 7.4, 5.8, 64.3, and 14.5 g/100 g dry fruit, respectively. Average values of fruit diameter, number of seeds, juice yield, soluble solids, and pH were determined as 5 mm, 17, 59.2%, 15.5 °Brix, and 4.3, respectively. Total phenolic compounds amounted to 2543 mg/100 g dry weight, anthocyanins to 561 mg C3G/100 g dry weight, and carotenoids to 43.3 mg/100 g oil. ORAC and DPPH values were 36.0 and 15.8 mmol TE/100 g dry weight, respectively. Linoleic acid predominated in a lipid profile that exhibited a good ω-6/ω-3 ratio (1.37). The structure of the berry consisted of a skin (exocarp) and a pulp (mesocarp) that contained many seeds representing 54% of the weight of the berry. These characteristics of *R. magellanicum* are similar to other wild Patagonian berries that have found applications as foods due to their convenience and the presence of abundant bioactive compounds.

Keywords

Ribes magellanicum, antioxidant activity, bioactive compounds, fatty acids, microstructure

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INTRODUCTION

Ribes magellanicum Poiret of the family Grossulariaceae genus *Ribes*, known locally as wild zarzaparilla or "*parra*," is a deciduous shrub growing in Chile from the Metropolitan Region (*ca*. 33°10'S) to south of the Beagle Channel (*ca*. 55°07'S) (Bañados et al., 2002; Domínguez et al., 2021). *R. magellanicum* is naturally distributed in Patagonia in clearings of forests of beech trees *Nothofagus pumilio* (Arena et al., 2007). The fruits are globose and fleshy berries, arranged as clusters and purple at maturity (Figure 1).

Rozzi et al. (2008) hypothesize that the Spanish Conquistadors related the abundant shrub with a weed (*zarza*), and the shape of its leaves reminded them of a small grapevine (*parrilla*), so they called the shrub "*zarza-parrilla*." Anglican missionaries in the late XIX century referred to this berry as "wild currant." because it looked like currants growing wild in their native countries. It is often confused with the cultivated and commercial red zarzaparilla (*Ribes rubrum*), *grosella roja* in Spanish or red currant in English, introduced in Chile by European immigrants (McLeod et al., 2014). Other Patagonian berries such as maqui (*Aristotelia chilensis*), calafate (*Berberis*

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[1]Department of Chemical and Bioprocess Engineering, Pontificia Universidad Católica de Chile, Santiago, Chile
[2]Department of Analytical Chemistry, Nutrition and Food Science, Food Technology Division, School of Veterinary Sciences, Universidad de Santiago de Compostela, Lugo, Spain

Corresponding author:
José M Aguilera, Department of Chemical and Bioprocess Engineering, Pontificia Universidad Católica de Chile, Vicuña Mackenna 4860, Santiago, Chile.
Email: jmaguile@uc.cl

Figure 1. Berries of *Ribes magellanicum* growing near Punta Arenas, Chile.

microphylla), and murta (*Ugni molinae*) have recently received much attention due to their attractive appearance and flavor. These berries exhibit potential as functional foods due to their high antioxidant capacity and have found applications as commercial products and in gastronomy, being used in the form of fresh fruits, juices, jams, syrups, and teas (Fuentes et al., 2019; Schmeda-Hirschmann et al., 2019).

Berries are highly regarded as convenient, flavorful, and healthy fruits that may prevent or delay some chronic diseases attributed to oxidative stress and inflammation. Moreover, berries are low in calories, and contain dietary fibers, vitamins, and bioactive phytochemicals (Aguilera, 2024). Worldwide, several wild berries contribute to food security and a healthy diet for the native population. Underutilized wild berry species have nutritional and food potentials, yet many of these small fruits go largely unpicked or are lost to different natural predators (Aguilera and Toledo, 2022). Like most other wild Patagonian berries, the fruit of *R. magellanicum* is recollected and consumed fresh by local people and used to produce various foods such as jams, juices, teas, and preserves, although its commercialization is not yet massive (Domínguez et al., 2021; Ochoa et al., 2019).

There is a need to increase the consumption of fruits in Western diets, which now stands below 20% of the recommended daily intake (Bajramova and Spégel, 2022). It is also important to incorporate new sources of wild small fruits in human nutrition, particularly those having a high antioxidant capacity provided by flavonoids and phenolic acids (Aguilera and Toledo, 2022). In this respect, more information should become available regarding the nutritional and physicochemical aspects of local wild berries. Thus, the objectives of this study were threefold: (i) to characterize the chemical composition of berries of *R. magellanicum*, including their content of bioactive compounds and antioxidant capacity; (ii) to assess their physicochemical properties as food (i.e. juice yield, color); and (iii) to investigate their microstructural aspects.

MATERIALS AND METHODS

Raw material and reagents

The berries of *Ribes magellanicum* (approximately 1 kg) were manually collected on March 21, 2022, from a single shrub growing naturally in a clearing of a *Nothofagus* forest in the Reserva Nacional Magallanes, (53°08′46″S; 71°00′12″W). Immediately after picking, fruits were frozen at −20 °C in a horizontal freezer (Mademsa, model M300, China) and transported to our laboratory. For analytical determinations, the frozen fruits were thawed at room temperature (20 °C) overnight, manually ground in a mortar, immersed in liquid nitrogen for 5 min, and freeze-dried for 24 h in a laboratory-scale equipment (Labconco, model Freeze Dryer 4.5, Kansas City, USA) with a condenser temperature of −45 °C and a vacuum level of 0.5 Pa. Methanol, n-hexane ≥97.0%, 2-propanol ≥99.5%, petroleum ether, Folin–Ciocalteu phenol reagent, gallic acid, and boron trifluoride in methanol were acquired from Calbiochem Merck (Darmstadt, Germany); fluorescein, 6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid (Trolox), 2,2-diphenyl-1-picrylhydrazyl (DPPH), and Azobis (2-methylpropionamidine) dihydrochloride (AAPH) were obtained from Sigma-Aldrich (St. Louis, MO, USA).

Physicochemical determinations

Twenty berries were randomly selected and characterized. Their weight and equatorial diameter were measured using an analytical balance (UX620H, Shimadzu, Kyoto, Japan) and a caliper. Seeds per berry were counted after manual separation from the pulp. Juice was obtained by pressing fruits to 95% strain using a texture analyzer (TA.XTplus, Stable MicroSystem Ltd, Godalming, UK). Juice yield was determined by subtracting spent solids mass from initial berries mass. Soluble solids were measured with a digital refractometer (Fd-tpz, Huaqin Zhongyuan, Shangdom, China) with ±0.2 °Brix precision. Juice pH was measured using a pH meter (PHS-3D, Shanghai San-Xin Instrumentation Inc., Shanghai, China). A digital vision system (DVS-Lab) captured images of berries and juice for color analysis, expressed in CIELab space, as described by Quevedo et al. (2008).

Analytical procedures

Proteins, lipids, ash, and crude fiber were determined according to AOAC methods (AOAC, 2005). Nitrogen-free extract (NFE) was calculated by difference and the energy content according to FAO (2003). Fruit juice was clarified and hydrolyzed following the method of Foitzich (2013). Total sugars of clarified juices were determined according to Schmidt-Hebbel et al. (1981) and expressed as mass of glucose equivalents per unit weight of sample. Glucose and fructose were determined according to Sainz et al. (2022) using a high-performance liquid chromatography system (HPLC) (Thermo Scientific Ultimate 3000, Germering, Germany) with a refractive index detector (Shodex RH-101, Yokohama, Japan). All analytical determinations were performed in duplicate or triplicate.

Extraction procedure and determination of total phenolics, anthocyanins, and antioxidant capacity

Extraction was performed according to Basegmez et al. (2017). One gram of freeze-dried berry pulp was mixed with 0.25 g of celite, and placed in an extraction column (Dionex ASE 300, Thermo Fisher Scientific, Waltham, MA, USA). Extraction was carried out in triplicate with 40 mL of water in 3 cycles of 5 min each, at 1500 psi and 40 °C, and the extracts were stored at −20 °C in a freezer (FDV, model STYLE SF170, Chile). Total phenolic content was determined following the Folin–Ciocalteu method, according to Singleton and Rossi (1965). The absorbance was measured at 765 nm in a spectrophotometer (UNICAM UV3 UV-Vis, Gemini, Apeldoorn, The Netherlands) and results expressed in mg GAE per 100 g of dry sample.

Antioxidant capacity

Oxygen radical absorbance capacity (ORAC). ORAC antioxidant capacity by was determined according to Huang et al. (2002) by recording the fluorescence intensity every 1 min using a 485-nm excitation filter with a 20-nm bandwidth, and a 528-nm emission filter with a 20-nm bandwidth in a fluorimeter (BioTek FLx800, Waltham, MA, USA). The kinetic variation of the fluorescence intensity of the samples and the Trolox standard solution (linear range between 12.5 and 100 µM ($R^2 > 0.99$)), were plotted. The ORAC values were expressed as mmol of Trolox equivalent (TE) per 100 g of dry sample.

2,2-Difenil-1-picrylhydrazylo (DPPH). Antioxidant capacity by DPPH was determined following the method proposed by Brand-Williams et al. (1995). The samples were kept in the dark for 30 min at room temperature (20 °C) before measuring the absorbance with a spectrophotometer. Results were expressed in mmol TE per 100 g of dry sample based on a Trolox calibration curve with a linear range between 10 and 150 ppm ($R^2 > 0.99$). Measurements were performed in triplicate.

Anthocyanins (ACN) by pH differential

The monomeric ACN content was determined by the pH differential method described by Giusti and Wrolstad (2001). The absorbances were read at 530 and 700 nm. The anthocyanin content was calculated as cyanidin 3-glucoside equivalents (EC-3G) using an extinction coefficient (ϵ) of 26,900 L/cm-mol and a molecular weight (MW) of 449.2 (g/mol). ACN contents were expressed as EC-3G (mg/mL). Measurements were performed in triplicate.

Tocols

Tocopherols and tocotrienols were determined by HPLC according to the official method Ce 8-89 (AOCS, 1998). A LiChro-CART Superspher Si 60 column (25 cm × 4 mm id, 5 µm particle size; Merck, Darmstadt, Germany) was used. The mobile phase was propan-2-ol in hexane (0.5/99.5 v/v) at a flow rate of 1 mL/min. Tocols contents were determined using tocopherol and tocotrienol standards. Results were expressed in mg TE/100 g oil.

Fatty acid composition

A gas chromatograph (GC-2014, Shimadzu Corp., Tokyo, Japan) was used to determine the fatty acids profile, according to the official method Ce 2-66 (AOCS, 2017). An FID detector, auto injector AOC-20i (Shimadzu Corp., Tokyo, Japan), and a fused silica capillary column SP2560 (Supelco, Bellefonte, PA, USA). The temperature was rised from 160 °C to 230 °C at 2 °C/min, and 0.5 µL simples were run with hydrogen as carrier gas. The reference standard NU-CHECK GLC463 was used to identify the FA profiles by comparing the retention times. To obtain methyl esters, the methylation method was used according to Ortiz-Viedma et al. (2023).

Total carotenoids content

Total carotenoid content of oil extracts was carried out according to Jaeger de Carvalho et al. (2012), with some modifications. A sample of 0.100 g of oil was weighed and brought to 10 mL with petroleum ether and read at 470 nm in a spectrophotometer. The total carotenoid content (µg/g) was calculated considering absorbance, final volume, sample weight, and lycopene extinction coefficient in petroleum ether.

Micro-CT image acquisition and reconstruction

Fresh and freeze-dried fruits were observed by high-resolution micro-computed tomography (CT) in a model X-ray equipment (Skyscan 1272, Bruker Corp., Kontich, Belgium). Samples were fixed to a holder and scanned for 0–360° with a rotation step of 0.2°, 0.9 s exposure time per frame, with a source voltage of 42 kV, a current of 195 µA, and a pixel size of 5 µm. No filters were used during the scanning and image reconstruction was performed with the equipment software (SkyScan, NRecon version 1.7.4.2., Bruker Corp., Kontich, Belgium), setting beam-hardening to 50%, smoothing in 1, and adjusting post-alignment and ring artifact correction.

RESULTS AND DISCUSSION

Chemical composition

Table 1 presents the results of proximate analysis, sugar content, and energy value for raw *R. magellanicum berries*, showing an average moisture content of 79.3% on a wet basis (w.b.). Variations in moisture content, ranging from 76% to 86% (w.b.), as reported in previous studies (Domínguez et al., 2021) likely stem from differences in growth location and harvesting time. The protein content of *R. magellanicum* was 7.4 g/100 g dry fruit, similar to findings by Domínguez et al. (2021) of 8.8 g/100 g dry fruit. The lipid content was 5.5 g/100 g dry fruit, contrasting with the 8.8 g/100 g dry fruit reported by Domínguez et al. (2021), possibly due to sample disparities and variations in lipid extraction procedures such as grinding and solvent type (Tischer et al., 2017). Piskernik et al. (2018) noted that the oil content in seeds (not the fruit) of *Ribes* species ranged between 17.8% and 22.4%.

The crude fiber content was 14.5 g/100 g dry fruit, while NFE was 68.2 g/100 g dry fruit (Table 1). NFE, derived from the difference between the sample weight and the combined weights of moisture, lipids, protein, crude fiber, and ash, encompasses soluble sugars, polysaccharides, pectins, gums, mucilages, and polyphenols (Saura-Calixto et al., 1983). Excluding the sugar content, approximately 4.2 g/100 g dry fruit of unidentified chemical compounds in the NFE likely represent structural polysaccharides. Dietary fiber, abundant in various berries and by-products of processing, is an important nutritional component (Alba et al., 2019); thus further research should be carried out regarding the soluble and insoluble dietary fiber content in *R. magellanicum*.

The total sugar content (64.3 g/100 g dry fruit or 13.3 g/100 g fresh fruit) was higher than in *U. molinae* (8.2 g/100 g fresh fruit) but similar to *B. microphylla* (13.9 g/100 g fresh fruit) (Romero et al., 2019). Predominant sugars included glucose (24.1 g/100 g dry fruit) and fructose (25.8 g/100 g dry fruit), with a glucose/fructose ratio of 0.9, close to the 1.1 ratio in *A. chilensis* (Brauch et al., 2016) but different from the 1.7 to 7.0 ratio found in *B. microphylla* by Ruiz et al. (2010).

R. magellanicum berries exhibited a calculated energy content of 73.1 kcal/100 g fresh fruit, surpassing strawberries (32 kcal/100 g fresh fruit), blackcurrants (56 kcal/100 g fresh fruit), and numerous other berries (Golovinskaia and Wang, 2021), still rendering them a low-calorie food (Aguilera and Toledo, 2022).

Physical and physicochemical characterization

Results of the physical characterization of *R. magellanicum* berries are shown in Table 2. The average weight of the raw fruit was 0.3 g, which is in the range of 0.1 to 0.3 g previously reported (Arena and Coronel, 2011; Damascos and Arribere, 2008). The average equatorial diameter was 0.5 cm, similar to the 0.6 cm reported by Damascos and Arribere (2008) and the 0.5 to 0.8 cm determined by Lediuk et al. (2014). On average, berries contained 17 seeds per berry, a value that is within the range of 13 and 18 seeds per berry reported by Lediuk et al. (2014) and Damascos and Arribere (2008). Arena and Coronel (2011) determined that 56 days after full bloom the berries reached a maximum of 23 seeds and decreased to 16 seeds per fruit 42 days later. When compared to other wild berries grown in Patagonia, *R. magellanicum* contains significantly more seeds, and the percentage of dry seed weight/dry fruit weight may reach 78.7% after 98 days from blooming (Arena and Coronel, 2011). Our result of 54% for the ratio of dry seeds to dry fruit (by weight) is consistent with values between 43% and 60% on a dry basis

Table 1. Mean values of moisture content, proximate analysis, sugars, and energy of *R. magellanicum* berries.

Moisture content (% w.b.)	
Raw	79.3 ± 0.8
Freeze-dried	12.6 ± 0.8
Proximal analysis (g/100 g dry fruit)	
Protein	7.4 ± 1.6
Lipids	5.8 ± 1.3
Crude fiber	14.5 ± 3.2
Ash	4.1 ± 0.9
NFE	68.2 ± 14.9
Total sugars (g/100 g dry fruit)	64.3 ± 0.3
Fructose	25.8 ± 2.2
Glucose	24.1 ± 0.6
Energy (kcal/100 g fresh)	73.4 ± 0.5

Table 2. Physicochemical parameters of fruits of *R. magellanicum*.

Raw fruit	Weight (g)		0.3 ± 0.1
	Diameter (cm)		0.5 ± 0.1
	Number of seeds		17 ± 4.3
	Seed/dry fruit ratio (%)		54.0
	Color	*L**	28.0 ± 0.9
		*a**	16.9 ± 1.8
		*b**	5.9 ± 1.0
Extracted juice	Yield (%)		59.2 ± 1.7
	Soluble solids (°Brix)		15.5 ± 0.1
	pH		4.3 ± 0.02
	Color	*L**	37.3 ± 3.9
		*a**	5.8 ± 2.3
		*b**	1.3 ± 2.3

reported by Lediuk et al. (2014). The large number of seeds and the high seed-to-fruits ratio in *R. magellanicum* make them attractive as a potential source of specialty oils given their unique fatty acid profile with interesting minor components (Alves et al., 2021; Van Hoed et al., 2009).

Characterization of the juice

Berry juices are attractive products due to their flavor and nutritional properties (Aguilera, 2024) Mechanical cold pressing is a conventional technology to extract juice from berries (Leong and Oey, 2017). The juice of *R. magellanicum* berries extracted by compression amounted to 59.2% by weight of raw fruit (Table 2), a value that is a proxy of how much juice could be obtained by cold pressing. The juice had an average of 15.5 °Brix, similar to the 14.3 °Brix reported by Domínguez et al. (2021) but slightly lower than the 17.5 °Brix informed by Arena and Coronel (2011). The average pH of the juice was 4.3 (Table 2), lower than the pH 5.0 measured for fully ripe berries of the same species (Arena and Coronel, 2011). Other juices from Patagonian berries have a lower pH, e.g. 3.9 for *A. chilensis* (Garrido et al., 2019) and 3.7 for *U. molinae* (Romero et al., 2019). As already stated, the physicochemical characteristics of berries from the same species are highly dependent on growing location, weather conditions, stage of maturity at harvest, and even on the location of fruits in the same branch (Mikulic-Petkovsek et al., 2016).

Color

Attractive color is one of the main sensory characteristics of berry products. Color coordinates of *R. magellanicum* berries and the extracted juice are shown in Table 2. Fresh berries are characterized by a dark-violet color (Figure 1), with a lightness L^* of 28 (closer to black than to white) and average a^* and b^* values of 16.9 and 5.9, respectively. In the juice, lightness increased and a^* and b^* values were reduced meaning that the outer skin of the fruit contributed with dark-colored pigments. The main compounds responsible for the blue and purple color in berries are the water-soluble anthocyanins (Vilela and Cosme, 2016). Natural colorants from berries are actively sought after as replacers of synthetic food colors and for their therapeutical properties (Gonzalez de Mejia et al., 2020).

Table 3. Content of bioactive compounds and antioxidant activity of *R. magellanicum* berries, and comparison with the Patagonian berry *Berberis microphylla* (calafate).

	Ribes magellanicum	*Berberis microphylla*
Total phenolics (mg GAE/100 g d.b.)	2543 ± 1.1[a]	1610–3490[b]
Total anthocyanins (mg C3G/100 g d.b.)	561 ± 36	1203–1373[c]
Total carotenoids (mg/100 g oil)	43.3 ± 1.7	n.a.
ORAC (mmol TE/100 g d.b.)	36.0 ± 1.9	46.7–72.4[d,e]
DPPH (mmol TE/100 g d.b.)	15.8 ± 3.4	7.2–8.6[c]

n.a.: not available.
[a]Total phenolics were measured in duplicate.
[b]Mariangel et al. (2013).
[c]Sanchez and Guzmán (2020).
[d]López et al. (2018).
[e]Garcia-Diaz et al. (2019).

Bioactive compounds

Several species of Patagonian berries contain bioactive compounds with potential health-promoting properties such as strong antioxidant activity and inhibitory inflammatory effects. The fruits of *B. microphylla* exhibit an exceptionally high antioxidant capacity which is attributed to the content of total polyphenols and anthocyanins (Aguilera and Toledo, 2022; Sanchez and Guzmán, 2020). Similarly, the potential beneficial effects of *R. magellanicum* berries have been largely attributed to the presence of phenolic acids and their derivatives, flavonoids, anthocyanins, and fatty acids (Schmeda-Hirschmann et al., 2019; Sun et al., 2021).

Table 3 shows the results of total phenolic compounds, anthocyanins, and carotenoids as well as *in vitro* antioxidant activity for the *R. magellanicum* berry, and reported data for *B. microphylla*. It is worth noticing that bioactive compounds and their antioxidant activity can vary significantly depending on genetics, farming methods, environmental factors, harvesting time, storage, processing conditions, and analytical methodologies (Kårlund et al., 2014).

The mean total phenolic content of fruits was 2543 GAE/100 g of dry fruit (575.2 mg GAE/100 g of fresh fruit), larger than previous reports for *R. magellanicum* (Jiménez-Aspee et al., 2016). Total phenolic compounds and anthocyanins were lower than fruits of *B. microphylla* (Table 3), but higher than that of other wild *Ribes* berries, such as wild strawberries (Aguilera and Toledo, 2022). Jiménez-Aspee et al. (2016) measured total phenolics of different *Ribes* berries in the south of Chile, finding that *R. magellanicum* had more phenolic compounds than *R. punctatum* and *R. trilobun*, but similar to *R. cucullatum*.

The average anthocyanin content of *R. magellanicum* was measured at 561 mg C3G/100 g of dry fruit (equivalent to 118 mg C3G/100 g of fresh fruit), which was lower than that of *B. microphylla* (refer to Table 3). When compared to other *Ribes* berries found in Chile, *R. magellanicum* exhibited a higher anthocyanin content than *R. punctatum* and *R.*

trilobum but significantly lower amounts than *R. cucullatum* (Jiménez-Aspee et al., 2016).

Carotenoids are recognized as potent antioxidants playing an important role in the prevention of some human diseases. The total carotenoid content was 43.3 ± 1.7 mg/100 g oil. Gross (1982) asserted that *Ribes* species have, in general, a low content of carotenoids. For a blue-violet cultivar of *Ribes grossularia* he reported a content of total carotenoids of 3.8 μg/g fresh weight. In a study involving several berries from Finland, Heinonen et al. (1989) reported that β-carotene and lutein were major carotenoids in black currant amounting to 539 μg/100 g fresh fruit.

Antioxidant capacity was assessed using both the ORAC and DPPH methods. In comparison to other berries, *R. magellanicum* exhibited lower antioxidant capacity than *B. microphylla* (Table 3) and *A. chilensis* (59.9 mmol TE/100 g d.b. by ORAC), but higher than *U. molinae* (16.2 mmol TE/100 g d.b. by ORAC) (López et al., 2021). Furthermore, when compared with other types of fruits such as apples, grapes, oranges, and plums, the antioxidant capacity of *R. magellanicum* berries was notably superior (at least one order of magnitude larger for ORAC determinations), consistent with the high antioxidant properties observed in berries (Wang et al., 1996).

Fatty acids

Berries are promoted as "superfruits" and claimed to confer superior health benefits than other fruits. Part of these positive effects is related to their FA profiles, although they differ widely among different berry species (Bajramova and Spégel, 2022). Table 4 lists major FA detected in *R. magellanicum* berries. Linoleic acid was the main FA (31.3%), followed by oleic acid (30.2%) and α-linolenic acid (22.8%). The most abundant polyunsaturated acids were two essential fatty acids for nutrition, linoleic acid and α-linolenic acid, while oleic acid is associated with a lower risk of coronary diseases. The FA profile of *R. magellanicum* compares well with that of cranberry, among many other berry oils (Tamkutė et al., 2020), and the total (54.1%) is similar to the content in *B. microphylla* (66.7%) and *A. chilensis* (43.6%) (Ortiz-Viedma et al., 2023). The ω-6/ω-3 ratio (1.37) is also comparable to that of the previously mentioned Patagonian PUFA berries and more favorable than the high average ratio present in most foods of the Western diet and associated with potential deleterious health effects (Ortiz-Viedma et al., 2023; Piskernik et al., 2018).

Table 4. Main fatty acids in *R. magellanicum* and saturated (SFA), mono- and poly-unsaturated FAs (MUFA and PUFA).

Fatty acid	Percentage
Myristic acid (C14:0)	< 0.1
Palmitic acid (C16:0)	12.3 ± 0.04
Palmitoleic acid (C16:1)	0.4 ± 0.1
Stearic acid (C18:0)	3.0 ± 0.1
Oleic acid (C18:1)	30.2 ± 0.2
Linoleic acid (C18:2) ω-6	31.3 ± 0.1
α-Linolenic (C18:3) ω-3	22.8 ± 0.1
SFA	15.3 ± 0.2
MUFA	30.6 ± 0.4
PUFA	54.1 ± 0.2
PUFA/SFA ratio	3.6
ω-6/ω-3 ratio	1.37

Tocopherols and tocotrienols

Vitamin E (represented by α-, β-, ϒ-, and δ-tocopherol, and α-, β-, ϒ-, and δ-tocotrienol) is an essential fat-soluble vitamin that modulates the immune function and acts as antioxidant (Andersson et al., 2008; Manful et al., 2023). It has been suggested that a daily serving of blueberries gives antioxidant protection to the skin due to the combined action of vitamins C and E (Ivarsson et al., 2023). The most abundant isomer in *R. magellanicum* was α-tocopherol as shown in Table 5.

Microstructure

While the anatomy of *R. magellanicum* berries has been described in the botanical literature, there is limited information on microstructural features, except for the wood (Pujana et al., 2008). X-ray micro-CT enables a thorough identification of internal structures in a non-invasive mode based on the attenuation of X-rays. Figure 2(a) depicts a three-dimensional volumetric reconstruction of a fresh *R. magellanicum* berry. The round shape of the fruit, its calyx (c), stem end (se), and the seeds (s) inside are clearly visible. In this fruit specimen 18 seeds were observed, with an average equatorial diameter of 1.2 ± 0.3 mm. Also noticeable is what appears to be an underdeveloped seed (us). As mentioned by Arena and Coronel (2011), not all seeds at the bloom phase grow during the fruiting period.

To further identify details, a freeze-dried berry was also studied and the histological interpretation is based on Laczkó-Zöld et al. (2019) for *Ribes nigrum* and *Ribes*

Table 5. Main tocopherols in *R. magellanicum* fruits.

	(mg/100 g oil)
α-Tocopherol	72.5 ± 0.3
β-Tocopherol	13.2 ± 0.3
ϒ-Tocopherol	39.7 ± 0.1
δ-Tocopherol	0.6 ± 0.0
ϒ-Tocotrienol	0.6 ± 0.0
Total tocopherols	126.6 ± 0.6

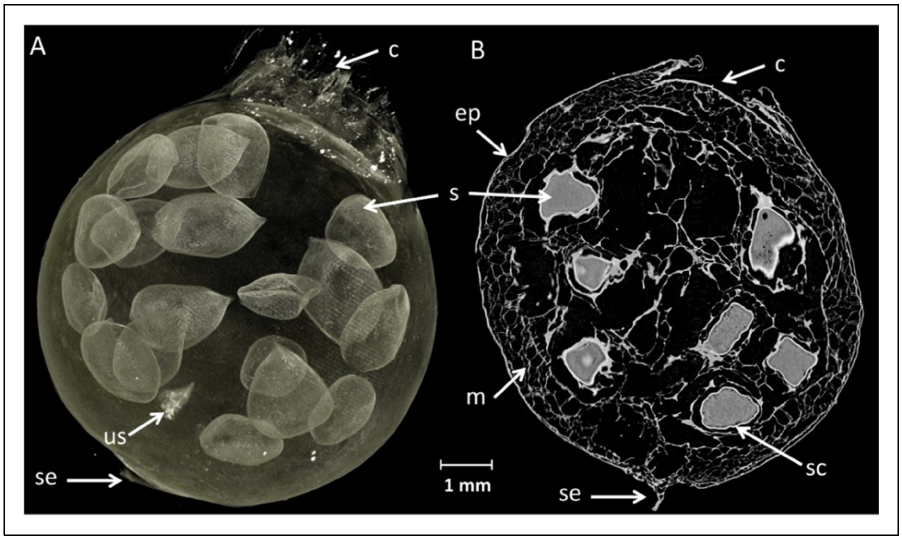

Figure 2. Microstructure of whole fruits of *R. magellanicum* observed by X-ray micro-CT. (a) Volumetric reconstruction of a raw fruit. (b) Sagittal cross-section of freeze-dried fruit. Arrows pointing to the calyx (c), seeds (s), epicarp (ep), mesocarp (m), stem end (se), undeveloped seed (us), and sclerenchyma cells (sc).

rubrum. The external skin or epicarp (ep) consisted of a large number of small cells forming a compact tissue (Figure 2(b)). The mesocarp (m) appears as a structure with cells larger than those of the epicarp. Cells of the mesocarp and epicarp maintain part of their cell walls intact, but closer to the fleshy center, they appear to collapse. In the freeze-dried fruit, the seeds (s) are covered by a dense layer of sclerenchyma cells (sc) that presumably constitutes a highly lignified tissue. Further work is being conducted to obtain relevant quantitative information of the microstructure of *R. magellanicum* berries and their seeds.

CONCLUSIONS

The Patagonian wild berry *R. magellanicum* has a long tradition of human consumption as food. Fruits from this plant contain abundant water and a low-fat content, thus can be classified as low-calorie foods. The NFE content probably corresponds to fiber that needs to be further analyzed and characterized for its nutritional and functional value. The content of phenolic compounds and anthocyanins, that may perform as strong antioxidants, is above mean values reported for other wild berries. Linolenic acid was the major FA and the lipid profile exhibited a favorable ω-6/ω-3 ratio of 1.76. Berries also contain tocopherols with vitamin E activity and carotenoids that may also act as antioxidants. The content of these compounds depends on the growing location, and environmental conditions and ripeness stage. *R. magellanicum* has great potential as fresh and processed fruits, similar to other commercial Patagonian berries. However, being a wild species, sustainability aspects are crucial given possible cultivation as a new crop.

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AUTHOR CONTRIBUTIONS

JMA contributed to conceptualization and methodology. JMA and MCM collaborated on writing and editing the main manuscript. MCM and CM conducted investigation tasks. MCM and TT curated the data. TT and CM performed analytical procedures. TT interpreted the data, while CM generated the data.

DECLARATION OF CONFLICTING INTERESTS

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ORCID iD

Claudia Matamala https://orcid.org/0009-0008-1579-4495

REFERENCES

Aguilera JM (2024) Berries as foods: processing, products, and health implications. *Annual Review of Food Science and Technology* 15: 1–26.

Aguilera JM and Toledo T (2022) Wild berries and related wild small fruits as traditional healthy foods. *Critical Reviews in Food Science and Nutrition* 14: 1–15.

Alba K, Campbell GM and Kontogiorgos V (2019) Dietary fibre from berry-processing waste and its impact on bread structure: a review. *Journal of the Science of Food and Agriculture* 99: 4189–4199.

Alves E, Simoes A and Domingues MR (2021) Fruit seeds and their oils as promising sources of value-added lipids from agro-industrial byproducts: oil content, lipid composition, lipid analysis, biological activity and potential biotechnological applications. *Critical Reviews in Food Science and Nutrition* 61: 1305–1339.

Andersson SC, Rumpunen K, Johansson E, et al. (2008) Tocopherols and tocotrienols in sea buckthorn (*Hippophae rhamnoides* L.) berries during ripening. *Journal of Agricultural and Food Chemistry* 56: 6701–6706.

AOAC (2005) *Official Method of Analysis*. Gaithersburg, MD: AOAC International.

AOCS (1998) *Official Methods and Recommended Practices*. Champaign, IL: The American Oil Chemist's Society.

AOCS (2017) *Preparation of Methyl Esters of Fatty Acids*. Champaign, IL: The American Oil Chemists' Society.

Arena ME, Bernini M and Vater G (2007) Growth and fruiting of *Ribes magellanicum* in Tierra del Fuego, Argentina. *New Zealand Journal of Crop and Horticultural Science* 35: 61–66.

Arena ME and Coronel LJ (2011) Fruit growth and chemical properties of *Ribes magellanicum* "parrilla". *Scientia Horticulturae* 127: 325–329.

Bajramova A and Spégel P (2022) A comparative study of the fatty acid profile of common fruits and fruits claimed to confer health benefits. *Journal of Food Composition and Analysis* 112: 104657.

Bañados MP, Hojas C, Patillo C, et al. (2002) Geographical distribution of native *Ribes* species present in the herbarium of Chile. *Acta Horticulturae* 585: 103–106.

Basegmez HIO, Povilaitis D, Kitrytė V, et al. (2017) Biorefining of blackcurrant pomace into high value functional ingredients using supercritical CO_2, pressurized liquid and enzyme assisted extractions. *The Journal of Supercritical Fluids* 124: 10–19.

Brand-Williams W, Cuvelier ME and Berset C (1995) Use of a free radical method to evaluate antioxidant activity. *LWT-Food Science and Technology* 28: 25–30.

Brauch JE, Buchweitz M, Schweiggert RM, et al. (2016) Detailed analyses of fresh and dried maqui (*Aristotelia chilensis* (mol.) stuntz) berries and juice. *Food Chemistry* 190: 308–316.

Damascos MA and Arribere M (2008) Native shrubs with fleshy fruits. Non-timber forest resources of the nothofagus dombeyi forest [los arbustos nativos con frutos carnosos. Recursos forestales no madereros del bosque de nothofagus dombeyi]. In: Second Meeting of Nothofagus in the Patagonia, EcoNothofagus 2008, Esquel, Argentina, pp.199–204.

Domínguez E, Lobos PL, Vergara C, et al. (2021) Wild zarzaparilla (*Ribes magellanicum* Poir.) edible native plant as potential new crop [Zarzaparrilla silvestre (*Ribes magellanicum* Poir.) planta nativa comestible como potencial nuevo cultivo]. (accessed 7 October 2023).

FAO (2003) *Food Energy—Methods of Analysis and Conversion Factors*.

Foitzich AC (2013) *Development and validation of a methodology to determine simple sugars in organic matrices using HPLC-IR [Desarrollo y validación de una metodología para determinar azúcares simples en matrices orgánicas mediante HPLC-IR]*. Valdivia, Chile: Universidad Austral de Chile.

Fuentes L, Figueroa CR, Valdenegro M, et al. (2019) Patagonian berries: healthy potential and the path to becoming functional foods. *Foods (Basel, Switzerland)* 8: 289.

Garcia-Diaz DF, Jimenez P, Reyes-Farias M, et al. (2019) A review of the potential of Chilean native berries in the treatment of obesity and its related features. *Plant Foods for Human Nutrition* 74: 277–286.

Garrido F, Sette P, Gallo L, et al. (2019) Optimized aqueous extracts of maqui (*Aristotelia chilensis*) suitable for powder production. *Journal of Food Science and Technology* 56: 3553–3560.

Giusti MM and Wrolstad RE (2001) Characterization and measurement of anthocyanins by UV-visible spectroscopy. *Current Protocols in Food Analytical Chemistry* 00: F1.2.1–F1.2.13.

Golovinskaia O and Wang C-K (2021) Review of functional and pharmacological activities of berries. *Molecules* 26: 3904.

Gonzalez de Mejia E, Zhang Q, Penta K, et al. (2020) The colors of health: chemistry, bioactivity, and market demand for colorful foods and natural food sources of colorants. *Annual Review of Food Science and Technology* 11: 145–182.

Gross J (1982) Chlorophyll and carotenoid pigments in *Ribes* fruits. *Scientia Horticulturae* 18: 131–136.

Heinonen MI, Ollilainen V, Linkola EK, et al. (1989) Carotenoids in Finnish foods: vegetables, fruits, and berries. *Journal of Agricultural and Food Chemistry* 37: 655–659.

Huang D, Ou B, Hampsch-Woodill M, et al. (2002) High-throughput assay of oxygen radical absorbance capacity (ORAC) using a multichannel liquid handling system coupled with a microplate fluorescence reader in 96-well format. *Journal of Agricultural and Food Chemistry* 50: 4437–4444.

Ivarsson J, Pecorelli A, Lila MA, et al. (2023) Blueberry supplementation and skin health. *Antioxidants* 12: 1261.

Jaeger de Carvalho LM, Barros Gomes P, de Oliveira Godoy RL, et al. (2012) Total carotenoid content, α-carotene and β-carotene, of landrace pumpkins (*Cucurbita moschata Duch*): a preliminary study. *Food Research International* 47: 337–340.

Jiménez-Aspee F, Theoduloz C, Vieira MN, et al. (2016) Phenolics from the Patagonian currants *Ribes* spp.: isolation, characterization and cytoprotective effect in human AGS cells. *Journal of Functional Foods* 26: 11–26.

Kårlund A, Moor U, Sandell M, et al. (2014) The impact of harvesting, storage and processing factors on health-promoting phytochemicals in berries and fruits. *Processes* 2: 596–624.

Laczkó-Zöld E, Komlósi A, Varga E, et al. (2019) Comparative histological evaluation of the fruit of *Ribes nigrum* and *Ribes rubrum*. *Acta Biologica Marisiensis* 2: 5–14.

Lediuk KD, Damascos MA, Puntieri JG, et al. (2014) Differences in phenology and fruit characteristic between invasive and native woody species favor exotic species invasiveness. *Plant Ecology* 215: 1455–1467.

Leong SY and Oey I (2017) Berry juices. In: Aguiló-Aguayo I and Plaza L (eds) *Innovative Technologies in Beverage Processing*, 1st ed. Chichester, UK: John Wiley & Sons Ltd., 131–203.

López J, Vera C, Bustos R, et al. (2021) Native berries of Chile: a comprehensive review on nutritional aspects, functional properties, and potential health benefits. *Journal of Food Measurement and Characterization* 15: 1139–1160.

López MD, Baenas N, Retamal-Salgado J, et al. (2018) Underutilized native biobío berries: opportunities for foods and trade. *Natural Product Communications* 13: 1934578X1801301226.

Manful CF, Hameed A, Thomas RH (2023) Chapter 6. Berries. In: Zabetakis I, Tsoupras A, Lordan R, et al. (eds) *Functional Foods and Their Implications for Health Promotion*. Cambrigde, MA, United States: Academic Press, 161–217.

Mariangel E, Reyes-Diaz M, Lobos W, et al. (2013) The antioxidant properties of calafate (*Berberis microphylla*) fruits from four different locations in southern Chile. *Ciencia e Investigación Agraria* 40: 161–170.

McLeod C, Pino MT, Ojeda A, et al. (2014) Relevant aspects of tunnel production of red zarzaparilla (*Ribes rubrum*) [Aspectos relevantes de la producción de zarzaparrilla roja (*Ribes rubrum*) bajo túne] (accessed 26 January 2023).

Mikulic-Petkovsek M, Koron D and Veberic R (2016) Quality parameters of currant berries from three different cluster positions. *Scientia Horticulturae* 210: 188–196.

Ochoa JJ, Moncunill EL, Puntieri JG, et al. (2019) Local knowledge and edible fruits of native plants in the 42° Parallel Andean Region (Patagonia, Argentina) [Saberes locales y frutos comestibles de plantas nativas en la Comarca Andina del Paralelo 42° (Patagonia, Argentina)]. *Ethnoscientia* 4: 1–9.

Ortiz-Viedma J, Bastias-Montes JM, Char C, et al. (2023) Sequential biorefining of bioactive compounds of high functional value from calafate pomace (*Berberis microphylla*) using supercritical CO_2 and pressurized liquids. *Antioxidants* 12: 323.

Piskernik S, Vidrih R, Demšar L, et al. (2018) Fatty acid profiles of seeds from different Ribes species. *LWT-Food Science and Technology* 98: 424–427.

Pujana R, Burrieza H and Castro M (2008) Wood anatomy of *Ribes magellanicum* (Grossulariaceae). *Boletín de la Sociedad Argentina de Botánica* 43: 61–65.

Quevedo RA, Aguilera JM and Pedreschi F (2008) Color of salmon fillets by computer vision and sensory panel. *Food and Bioprocess Technology* 3: 637–643.

Romero ME, Noriega F, Farías M, et al. (2019) New sources of natural antioxidants: characterization of bioactive compounds in five native Chilean fruits [Nuevas fuentes de antioxidantes naturales: Caracterización de compuestos bioactivos en cinco frutos nativos de Chile]. *Perfiles* 2: 34–41.

Rozzi R, Arango X, Massardo F, et al. (2008) Field environmental philosophy and biocultural conservation: the Omora Ethnobotanical Park educational program. *Environmental Ethics* 30: 325–336.

Ruiz A, Hermosín-Gutiérrez I, Mardones C, et al. (2010) Polyphenols and antioxidant activity of calafate (*Berberis microphylla*) fruits and other native berries from southern Chile. *Journal of Agricultural and Food Chemistry* 58: 6081–6089.

Sainz F, Pardo J, Ruiz A, et al. (2022) Use of non-conventional yeasts to increase total acidity in the Cava base wines. *Food Science and Technology* 158: 113183.

Sanchez R and Guzmán C (2020) Description of the antioxidant capacity of calafate berries (*Berberis microphylla*) collected in southern Chile. *Food Science and Technology (Campinas)* 41: 864–869.

Saura-Calixto F, Cañellas J and Soler L (1983) Dietary fibre and components of the nitrogen-free extract of almond kernels. *Journal of the Science of Food and Agriculture* 34: 1419–1422.

Schmeda-Hirschmann G, Jiménez-Aspee F, Theoduloz C, et al. (2019) Patagonian berries as native food and medicine. *Journal of Ethnopharmacology* 241: 111979.

Schmidt-Hebbel H, Avendaño S, Pennacchiotti I, et al. (1981) *Advances in Science and Food Technology [Avances en ciencia y tecnología de los alimentos]*. Santiago, Chile: Universidad de Chile.

Singleton VL and Rossi JA (1965) Colorimetry of total phenolics with phosphomolybdic-phosphotungstic acid reagents. *American Journal of Enology and Viticulture* 16: 144–158.

Sun Q, Wang N, Xu W, et al. (2021) Genus *Ribes* Linn. (Grossulariaceae): a comprehensive review of traditional uses, phytochemistry, pharmacology and clinical applications. *Journal of Ethnopharmacology* 276: 114166.

Tamkutė L, Liepuoniūtė R, Pukalskienė M, et al. (2020) Recovery of valuable lipophilic and polyphenolic fractions from cranberry pomace by consecutive supercritical CO_2 and pressurized liquid extraction. *The Journal of Supercritical Fluids* 159: 104755.

Tischer B, Vendruscolo RG, Wagner R, et al. (2017) Effect of grinding method on the analysis of essential oil from *Baccharis articulata* (Lam.) Pers. *Chemical Papers* 71: 753–761.

Van Hoed V, De Clercq N, Echim C, et al. (2009) Berry seeds: a source of specialty oils with high content of bioactives and nutritional value. *Journal of Food Lipids* 16: 33–49.

Vilela A and Cosme F. (2016) Drink red: phenolic composition of red fruit juices and their sensorial acceptance. *Beverages* 2: 29.

Wang H, Cao G and Prior RL (1996) Total antioxidant capacity of fruits. *Journal of Agricultural and Food Chemistry* 44: 701–705.