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Chilean Endemic/Native Plant Resources as Functional and Superfoods

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Additional information is available at the end of the chapter

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Abstract

The current consumer demand for foods or food supplements with "super properties" is being covered by previously under-exploited ethnic products. The endemic flora from multiple continents serve as source of plant foods such as cereals or tropical fruits. Chile, one of the top five plant biodiversity hotspots on the planet, is a promising source of functional foods with little scientific and commercial research. The aim of this chapter is to summarize the findings related to the antioxidant and antibacterial potential of native/endemic plants and plant-derived compounds from Chile. Resources of these compounds may be found in honey, bee pollen, and berry-like fruits. These products, unknown to many parts outside the country, not only have the advantage of their functional properties but also possess denomination of origin, which gives added value and allows them to be used as food additives such as natural colorants, antioxidants, antibacterials, and antifungals. In the coming years, many of these products will be more commercially known and many of these plant species will be selected and improved, as have happened with products such as tofu or blueberries.

Keywords: biodiversity, endemism, berries, honey, bee pollen, antioxidant, antibacterial

1. Introduction

The latest food consumer trends point beyond fulfilling the function of providing nutrients to the body. It is intended that foods provide compounds capable of reducing the likelihood of developing diseases, improving or complementing the functions of the body, and even increasing life expectancy. A search for new food sources of these "healthy compounds" is

underway to meet the needs of today's consumers. New analytical methods are being used with known foods to demonstrate properties they always had, but properties that had not been properly tested because of technological limitations; new foods or derived food compounds are also being found.

The diversity of food we know is derived from the biodiversity of plant and animal species we know. However, there are still many plant species which have not been explored or whose potential is just beginning to come to light. Many of these plants have been used by aboriginal groups around the world since ancient times. These species, which only grow in specific geographic locations (endemism), are rarely objects of scientific study or for industrial or commercial scaling.

Chile is one of the top five hotspots of plant biodiversity on the planet; here it is possible to find new food and food-derived resources of interesting compounds in the poorly explored flora. In addition, the biodiversity of plant species found in Chile have a high degree of endemism, indicating that they do not grow elsewhere. Leaves, stems, roots, or fruits can be sources of antioxidants and/or antibacterial compounds. Among the plant species with potential are the non-fruiting tree specimens such as quillay and ulmo; within fruit tree species, we may find maqui, murta, calafate, and others that are less known. All these products have high contents of polyphenolics, which have high antioxidant and antibacterial properties.

Polyphenolics are secondary metabolites from plants that have been associated with several healthy benefits such as the prevention of cancer, cardiovascular, inflammatory, and neuro-degenerative diseases [1–3]; they are also associated with bioactive properties such as antioxidant and antibacterial properties [4–7].

Each phenolic/flavonoid compound has different antioxidant/antibacterial potency depending on its action mechanism. Phenolic compounds alter the permeability of bacterial cell membranes, which may result in the uncoupling of oxidative phosphorylation, the inhibition of active transport, and the loss of pool metabolites due to cytoplasmic membrane damage [8, 9]. Other authors explain the antibacterial activity of phenolics by the presence of more number of hydroxyl groups that may form hydrogen bonds with enzymes, altering their metabolism and also the lipid solubility and the degree of steric hindrance [10, 11]. In the case of flavonoids, antibacterial activity has been associated with its capacity to form complex bonds with proteins through non-specific forces such as hydrogen bonding and hydrophobic effects, as well as by covalent bond formation. Thus, it may inactivate microbial adhesins, enzymes, and cell envelope transport proteins. Lipophilic flavonoids may also disrupt microbial membranes [12, 13].

2. Effect of endemic/native Chilean plants on the functional activity of honeybee products

Honey has been recognized for many centuries as a healthy food, because of its positive effects such as healing [14], anti-inflammatory [15], antibacterial [16–20], and antioxidant [20–24]

properties; and prebiotic capacity [24–28]. Meanwhile, the pollen has also been recognized by health claims. Scientific studies have been shown that bee pollen acts as an anti-anemic, tonic and restorative, hormonal and intestinal regulator, vasoprotector, hepatoprotective and detoxifying agent, and antioxidant and antibacterial [29, 30]. All these properties vary with the botanical and geographical origin (**Table 1**).

Honey	Phenolic compound	References
Heather	Benzoic acid, phenyl acetic acid	[31, 32]
Heather	Mandelic acid, B-phenyllactic acid	[32]
Honeydew	Protocatechuic acid	[32]
Rape	Hydrocinnamic acid	[32]
Buckwheat	4-hydroxybenzoic acid	[32]
Honeydew	Protocatechuic acid	[33]
Chestnut	Ferulic acid, p-coumaric acid	[33]
Chestnut	4-hydroxybenzoic acid, 4-hydroxyphenyllactic acid, phenylacetic acid	[34]
Heather	B-phenyllactic acid, benzoic acid, phenyl acetic acid	[34]
Sunflower	p-coumaric acid, phenyllactic acid, caffeic acid	[34]
Lime	3-hydroxybenzoic acid	[34]
Lavander	Caffeic acid, gallic acid	[34]
Strawberry	Homogentisic acid	[35]
Heather	Ellagic acid, abscisic acid	[36, 37]
Eucaliptus	Abscisic acid, ellagic acid	[38]
Citrus	Hesperetin	[39]
Rosemary	Kaempferol	[40]
Sunflower	Quercetin	[36, 37]
Eucaliptus	Myricetin, tricetin, luteolin, quercetin	[38, 41]
Manuka	Methylglyoxal	[42]
Heather	p-hydroxybenzoic, vanillic, chlorogenic, caffeic, syringic. p-coumaric, ferulic, m-coumaric, o-coumaric, ellagic, cinnamic acids	[43]
Lavander	Gallic, vanillic, chlorogenic, p-coumaric, ferulic, m-coumaric, cinnamic acids	[43]
Black locust	p-hydroxybenzoic, vanillic, p-coumaric, ferulic, trans-cinnamic acids. Vanillin, pinobanksin, apigenin, kaempferol, pinocembrin, chrysin, acacetin	[44]

Honey	Phenolic compound	References
Acacia	Abscisic acid, p-hydroxybenzoic, vanillic, p-coumaric, Ferulic, trans-cinnamic acids. Vanillin, pinobanksin, apigenin, kaempferol, pinocembrin, chrysin, acacetin	[44]
Rosemary	Pinobanksin, quercetin, luteolin, 8-methoxykaempferol, kaempferol, apigenin, isohamnetin. quercetin 3,3'-dimethyl ether, pinocembrin, quercetin 7,3'-dimethyl ether, quercetin 3,7-dimethylether, chrysin, galangin, tectochrysin	[40]
Eucalyptus	Quercetin, luteolin, myricetin	[45]
Lotus	Quercetin, luteolin, myricetin	[45]
Buckwheat	3-hydroxybenzoic acid, chlorogenic acid, 4-hydroxybenzoic acid, vanillic acid, caffeic acid, syringic acid, ferulic acid, p-coumaric acid, rosmarinic acid, ellagic acid, myricetin, quercetin, kaempferol, chrysin, galangin	[45]
Sage	Myricetin, quercetin, luteolin, kaempferol, apigenin, isorhamnetin, chrysin, galangin, abscisic acid, caffeic acid, p-coumaric acid	[46]
Robinia	Myricetin, quercetin, luteolin, kaempferol, apigenin, chrysin, galangin	[47]
Eucalyptus	Myricetin, tricetin, quercetin, luteolin, quercetin-3-methyl ether, kaempferol, pinobanksin, chrysin, pinocembrin	[41]
Quillay	Chlorogenic, caffeic, coumaric, syringic, p-coumaric, vanillic and salicylic acids. Naringenin, quercetin, kaempferol	[48]
Ulmo	p-coumaric, ferulic, chlorogenic, caffeic, sinapic, syringic and salicylic acid Kaempferol luteolin	[49]

Table 1. Different polyphenolic compounds found in honeys with several botanical origins.

2.1. Honeys

Chilean honey has shown biological activity against bacteria and fungi. *Pseudomonas aeruginosa*, *Escherichia coli*, *Staphylococcus aureus*, *Streptococcus pneumoniae*, and *Vibrio cholerae* have been inhibited by hydroalcoholic extracts derived from honey [49, 50]. Meanwhile, *Candida albicans* has also shown sensitivity to Chilean honey. Chilean honey even has higher antimicrobial activity than Manuka honey, which has a standard antioxidant and antimicrobial activity potential [51]. The antimicrobial activity of honey is probably the result of the total number of active compounds and not the presence of any one of them (i.e., phenolics and flavonoids). This activity may be the result of synergism between flavonoids and phenolic compounds or between phenolic compounds and terpenes. Some phenolic compounds and flavonoids are present only in certain unifloral honeys. These results have allowed for the identification and certification of these honeys. References [48, 52, 53] identified chlorogenic, caffeic, coumaric, syringic, p-coumaric, vanillic and salicylic acids, naringenin, quercetin and kaempferol in the unifloral honey of Quillay (*Quillaja saponaria*). In the same report, [52] found p-coumaric, ferulic, and salicylic acids in the endemic unifloral honey of Ulmo (*Eucryphia cordifolia*). Pinobanksin and kaempferol are typically identified in Chilean honeys.

Other more recent Chilean honeys currently being studied are Avellano honey (*Gevuina avellana* Molina), Tiaca honey (*Caldcluvia paniculata* (Cav.) D. Don), and Corontillo honey (*Escallonia pulverulenta*), which have shown antibacterial and antioxidant properties [50].

2.2. Bee pollen

Bee pollen provides important ingredients to the human diet, such as carbohydrates, protein, fat, and other components in lesser amount such as minerals. Carbohydrates are mainly polysaccharides such as starch and sugars and represent between 13 and 55 g per 100 g of sample. With regard to protein content, bee pollen provides all essential amino acids to the human diet and their percentages vary between 10 and 40% of the test sample [55–63]. Referring to fats, a study reveals that 3% of the total lipids are free fatty acids and about half of them are omega-3 unsaturated oleic, linoleic (omega-6), and linolenic acids (omega-3) [55]. With reference to the mineral content, bee pollen contains potassium, phosphorus, calcium, magnesium, iron, copper, zinc, and selenium in amounts that satisfy the daily recommended intake per person [64].

Bee pollen classification	Total phenolics	FRAP	DPPH	β-Carotene	Lycopene	Total flavonoids	References
Pollen multiflora	–	–	–	17.05–489.20 µg/g	–	–	[63]
Pollen multiflora	–	–	–	1–20 mg/100 g	–	1293–8243 mg/100 g	[23]
Pollen multiflora	–	–	–	–	–	530–3258 mg/100 g	[71]
Pollen multiflora	–	0.25–5.35 mM Fe ²⁺ /g	0.27–2.8 mmol Trolox/g	–	–	–	[55]
Pollen multiflora	4.4–16.4 mg GAE/g	0.255–5.355 mM Fe ²⁺ /g	0.274–2.814 mmol Trolox/g	–	–	2.8–13.6 mg eq quercetin/g	[74]
Pollen multiflora	817,33–138367 mg tannin/kg	–	47,97–86,25 % of inhibition	–	–	–	[75]
<i>Quillaja saponaria</i>	18.15 mg GAE/g	34.48 mM Fe ²⁺ /g	2.97 mg ascorbic acid/g	0 µg/g	0 µg/g	–	[54, 76]
<i>Azara petiolaris</i>	16.43 mg GAE/g	14.58 mM Fe ²⁺ /g	2.86 mg ascorbic acid/g	13.60 µg/g	60.40 µg/g	–	
<i>Puya chilensis</i>	11.83 mg GAE/g	28.24 mM Fe ²⁺ /g	2.87 mg ascorbic acid/g	4.60 µg/g	14.70 µg/g	–	
<i>Cryptocarya alba</i>	11.74 mg GAE/g	28.32 mM Fe ²⁺ /g	3.06 mg ascorbic acid/g	0 µg/g	0 µg/g	–	
<i>Colliguaja odorifera</i>	11.50 mg GAE/g	46.39 mM Fe ²⁺ /g	2.87 mg ascorbic acid/g	7.10 µg/g	7.30 µg/g	–	
<i>Schinus polygamus</i>	7.12 mg GAE/g	24.85 mM Fe ²⁺ /g	2.93 mg ascorbic acid/g	25.40 µg/g	28.80 µg/g	–	

Table 2. Main antioxidant parameters and pigments presented in bee pollen from different resources.

Several reports demonstrate the health benefits of bee pollen. Scientific studies have shown that bee pollen acts as an anti-anemic, tonic and restorative, hormone regulator, intestinal regulator, vasoprotector, and hepatoprotective, detoxifying, and antioxidant agent [28, 29, 65]. However, very few studies have identified the phenolic compounds of Chilean bee pollen. The information on bee pollen production for food applications and some reports concerning their antimicrobial and antioxidant activity [54, 66, 67].

Phenolic acids, flavonoids, and pigments such as β -carotene are mainly responsible for the healthy properties such as antioxidant and antibacterial properties exhibited by bee pollen [68–70]. The phenolic acids and flavonoid glycosides are present in the nectar of flowers visited by bees, which are hydrolyzed and transferred to bee pollen. The number and variety of phenolic acids and flavonoids are highly variable, since beekeepers mix bee pollen with different botanical origins from different plant species [22, 71]. A major flavonoid found in bee pollen is rutin [72]. The main group of pigments that compose bee pollen are carotenoids, especially β -carotene, whose concentration also depends on the botanical origin of the sample [63]. The β -carotene content is about 17% of total carotenoids. In some cases, it may contain 20 times less carotenoids than some foods [73]. In Chilean bee pollen, the carotenoid content varies with the botanical origin (**Table 2**).

The type and concentration of the polyphenolic compound influence the antibacterial and antioxidant activity exhibited by bee pollen. The most important polyphenolic compounds related to these activities are vanillic acid, protocatechuic acid, gallic acid, p-coumaric acid, hesperidin, rutin, kaempferol, apigenin, luteolin, quercetin, and isorhamnetin [70]. Bee pollen rich in these compounds has shown activity against specific pathogens such as *S. aureus*, which causes skin infections; *E. coli*, which causes diarrhea [67, 77], *Streptococcus pyogenes*, which causes acute bacterial pharyngitis [78], *P. aeruginosa*, which produces tissue damage and affects the immune system [79] and *S. pyogenes*, which causes skin wounds [16]. Another important study demonstrated the inhibition activity against *Salmonella* spp., as shown **Figure 1** [66].

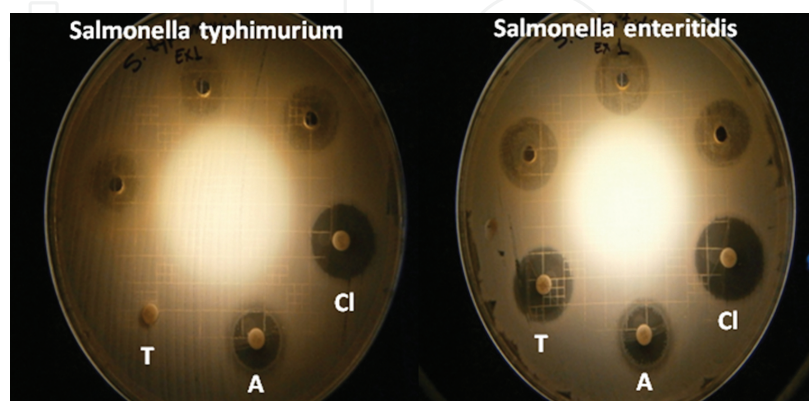


Figure 1. Antibacterial activity of Chilean multiflora bee pollen hydrophilic extracts evaluated by inhibition zone diameter against *Salmonella typhimurium* and *Salmonella enteritidis*. Tetracycline (T), ampicillin (A) and chloramphenicol (Cl) were used as controls.

3. Endemic/native berries

Chile is the main exporter of berries in the Southern Hemisphere and the fifth berry exporter worldwide because of its comparative advantages: geographic isolation of the country (desert in the north, the Pacific Ocean, the Andes mountains, and the Patagonian ice), which makes it an island from the health point of view, decreasing the incidence of pests and diseases; the Mediterranean climate is beneficial to obtain optimal raw material and production and in a counter-season and phased production [80, 81]. Maqui, murta, and others recently explored are included in the list of actual and future production (Figures 2 and 3).

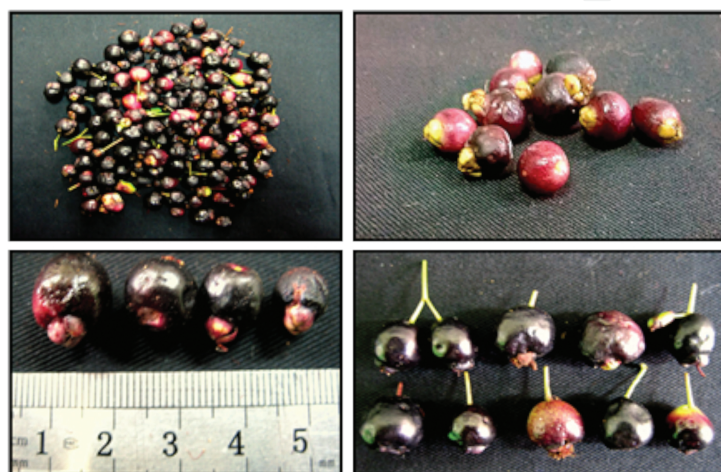


Figure 2. *Luma apiculata* or “arrayán” fruits. These berry-like fruits have higher antioxidant activity than blueberries. Many unknown Chilean endemic/native fruits are potential functional foods.



Figure 3. *Myrceugenia obtusa* or “Rarán” fruits. These berries have antioxidant and antibacterial activities (Orellana et al., 2017).

3.1. “Maqui” (*Aristotelia chilensis*)

Maqui is a berry with antioxidant and antihemolytic properties [82, 83], and it limits adipogenesis and inflammatory pathways *in vitro* [84, 85], protects against oxidative stress by reducing lipid peroxidation [86], inhibits LDL oxidation *in vitro* and protects human endothelial cells against oxidative stress [87] and has cardioprotective [88] and gastroprotective properties [89]. These healthy effects are produced by anthocyanins and many other bioactive compounds such as flavonoids, coumarins, phenolic acid (i.e. gallic, gentisic, sinapic, hydroxybenzoic, vanillic acids, makonine, 8-oxo-9 dehydrohobartine and 8-oxo-9 dehydromakomakine [90–93] present in the fruits. Recently, Maqui has been used to design new functional foods such as drinks and cakes with antioxidant properties for *in vivo* and clinical trials [94–96].

3.2. “Murta” or “murtilla” (*Ugni molinae*)

Murta fruits are berries which have a rich chemical composition of bioactive compounds associated with health properties [97]. They have shown analgesic *in vitro* activity [98], protective capacity against oxidative damage of human erythrocytes [99], antimicrobial activity [100], antioxidant activity [101, 102], and α -glucosidase/ α -amylase inhibition [102] as the main beneficial effects.

3.3. Other berries and berry-like fruits

“Calafate” (taxonomically described as *Berberis buxifolia* and also *Berberis microphylla*) fruits are berries that are scarcely studied. However, the available information is very interesting and indicates its potential as an antioxidant, which may be related to its high anthocyanin and hydroxycinnamic acid levels [103, 104]. Most recently, exploratory studies have revealed new native/endemic berry-like fruits such as *Luma apiculata*, *Ribes punctatum*, *Ribes magellanicum*, *Ribes cucullatum* and *Ribes tribolum* [105, 106]. *Ribes* spp., *Rubus* spp., *Gaultheria* spp., and *Berberis* spp., among others, as promising crops of functional foods or food additives/supplements such as natural colorants (Table 3). Some other non-scientific studies have been related with functional properties of several non-fruitle plants with anticoagulant, antithrombin, and analgesic properties and related health effects [107].

Common name	Scientific name	Attributed properties	Description	References
Chaura	<i>Gaultheria pumila</i>	Antioxidant (anthocyanin content)	The fruit is a berry, white or pink. ovoid shaped, 6 mm to 12 mm in diameter	[108]
Chaura	<i>Gaultheria mucronata</i>	Antioxidant	The fruit is a berry, between 6 and 9 mm in diameter, plum-shaped, passing from white to pink and finally to dark purple when ripe	[104, 109]
Chaura	<i>Gaultheria antarctica</i>	Antioxidant	The fruit is a berry, white or pink, ovoid shaped, 6 mm to 10 mm in diameter	[110]

Common name	Scientific name	Attributed properties	Description	References
Uva de cordillera, calafatillo	<i>Berberis empetrifolia</i>	Antioxidant	The fruit is a globose, blue-black, about 7 mm in diameter	[109, 110]
Calafate, chelia	<i>Berberis ilicifolia</i>	Antioxidant	Fruits are blue-black berries about 1 cm long, with four to six seeds, 5–6 mm in diameter	[110]
Calafate	<i>Berberis microphylla</i>	Antioxidant, antibacterial	The fruit is a spherical blue-black berry, about 1 cm. in diameter, and contains six angular seeds	[110–113]
Calafate	<i>Berberis buxifolia</i>	Antioxidant (anthocyanin content)	The fruit is a globose, blue-black, about 7–10 mm in diameter	[109, 114, 115]
Michay, mechay	<i>Berberis darwinii</i>	In vitro evidence for Alzheimer's disease therapy	The fruit is a globose, blue-black, about 7–10 mm in diameter	[116]
Copihue, Chilean bell national flower	<i>Lapageria rosae</i>	Antioxidant	The fruits are red berries, ovoid, between 3 and 6 cm long, with a thick skin containing numerous seeds	[117, 118]
Chilco, Chilca, Palo blanco	<i>Fuchsia magellanica</i>	Hypotensive and diuretic effect, antioxidant activity, significant inhibitory activity against B-glucuronidase enzyme	Fruit is a black berry, about 8–10 mm diameter	[104, 119–122]
Peumo	<i>Cryptocarya alba</i>	Significant inhibitory activity against B-glucuronidase enzyme, free radical scavenging activity, antibacterial activity	Red fruit with one large seed	[119, 123–125]
Daudapo, Huarapo, Zarapito, Té de la turba, naurapo, mirteola	<i>Myrteola nummularia</i>	Antioxidant (higher antioxidant content than blueberries), it may reduce colon cancer risk, source of natural colorant as anthocyanin	The fruit is up to 1 cm in diameter, it has a soft juicy flesh and a delicious slightly aromatic flavor	[104, 109, 126–128]
Copihuelo, Copihue chilote, Copihuelo, Coicopiu,	<i>Philesia buxifolia</i> , <i>Philesia magellanica</i>	Antioxidant	The fruit is a yellowish green ovoid berry, size up to 13 mm long	[121, 129]
Queule, keule,	<i>Gomortega nitida</i> , <i>Gomortega keule</i>	Antioxidant	The fruit is a drupe, yellow, about 34–45 mm (1.3–1.8 in) in diameter, usually with 1–2 seeds	[130]
Cauchao (from Luma or red	<i>Amomyrtus luma</i>	Antioxidant, inhibit	The fruit is a black to purplish-black berry when ripe, with about 1–1.5 cm in	[121, 131, 132]

Common name	Scientific name	Attributed properties	Description	References
Luma tree)		platelet aggregation (anticoagulant effect), antibacterial	diameter, generally with 3 seeds, about 3–4.5 mm	
Cauchao (from Meli or White Luma tree)	<i>Amomyrtus meli</i>	Antioxidant, antibacterial	The fruit is a black or purplish black Berry, 5–8 mm in diameter, generally with 3 seeds, about 3–4.5 mm	[112, 113, 132]
Chequén, Arrayán blanco, Arrayán	<i>Luma chequen</i> <i>Luma apiculata</i>	Antioxidant Antioxidant, antibacterial, inhibit platelet aggregation (anticoagulant effect)	The berry-like fruit (drupe) is a dark purple, about 1 cm in diameter Berry rounded black fruit, about 1.3–1.5 cm. diameter, containing three seeds	[112, 113, 133] [105, 112, 125, 131, 133]
Chilean strawberry, wild strawberry	<i>Fragaria chiloensis</i>	Antioxidant, free radical scavenging activity, anticancer cell Proliferation properties (human lung epithelial cancer cells)	The fruit is whitish or pale pink	[134–139]
Chañar, chañal	<i>Geoffroea decorticans</i>	Antioxidant, antinoceptive, anti-inflammatory activities; antitussive and expectorant significant effect, antibacterial	The berry-like fruit is a drupe, ovoid, red-brown when ripe, about 1.7–3.5 cm to 1.5 cm. The pulp is white-yellowish and has 1 or 2 seeds	[140–142]
Maqui	<i>Aristotelia chilensis</i>	Inhibidor de la enzima xantina oxidasa (síntomatología de la gota); antimicrobial activity (wound treatment); in vitro and in vivo antidiabetic effects, antibacterial activity, cardioprotective effects, antioxidant	The fruit is a small fleshy edible berry (green when unripe and purple black when ripe), about 5 mm, with 2–4 seeds	[82, 83, 86, 88, 90, 103, 143–146]
Murtilla de Magallanes, brecillo, uvilla	<i>Empetrum rubrum</i>	Antioxidant	Globose and fleshy fruit, about 8 mm in diameter, dark red	[109]
Murta, murtilla, Murta blanca, Tautau	<i>Ugni molinae</i>	Antioxidant, vasodilator activity, antibacterial	The fruit is a bright red berry, around 5–15 mm in diameter	[83, 99, 103, 112, 113, 147–149]
Zarzaparrilla, parrilla, uvilla, mulul, milul, Chilean currant	<i>Ribes punctatum</i> , <i>Ribes cucullatum</i> , <i>Ribes magellanicum</i> ,	Antioxidant, cytoprotective effect in human gastric cells	Fruits are red, black, or green	[104, 106]
Zarzaparrilla, parrilla, Chilean currant	<i>Ribes trilobum</i>	Antioxidant, cytoprotective effect in human gastric cells	The fruit is initially green and becomes glossy black when ripe	[106]

Common name	Scientific name	Attributed properties	Description	References
Zarzaparrilla, parrilla, Chilean currant	<i>Ribes valdivianum</i>	Antioxidant	Purple-black berry-like fruit	[150]
Zarzaparrilla, Miñe-miñe, strawberry of Magallanes, wild raspberry	<i>Rubus geoides</i>	Antioxidant, cytoprotective effect in human gastric cells	Berry-like fruit	[111, 151]

Table 3. Main functional properties of native/endemic berries and berry-like fruits.

4. Conclusions and future trends

In spite of the endemism, there are promising bee hive-derived products obtained from Chilean plants, as well as Chilean plant products in general. We are convinced that the main exponents of functional foods and super foods are in nature, which is where we have to explore to find them. However, they should be used and exploited in a sustainable way.

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