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Reviews

Berries from South America: A Comprehensive Review on Chemistry, Health Potential, and Commercialization

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ABSTRACT Dietary intake of berry fruits has been demonstrated to positively impact human health. Interest in exploring new and exotic types of berries has grown in recent years. This article provides botanical descriptions and reviews the chemistry, biological activities, and commercialization of berry-producing plants from South America, specifically *Aristotelia chilensis*, *Euterpe oleracea*, *Malpighia emarginata*, *Ugni molinae*, *Fragaria chiloensis*, *Rubus glaucus*, *Rubus adenotrichus*, and *Vaccinium floribundum.* These species possess a rich and diversified composition of bioactive compounds with health-promoting properties. The most significant health benefits have been attributed to phenolic compounds and vitamin C, potentially protective against cardiovascular disease and cancer. Although both traditional folk medicine and composition of these berries suggest significant health benefits, few studies to date have investigated these potentials.

KEY WORDS: • Aristotelia chilensis • *berries* • Euterpe oleracea • Fragaria chiloensis • *health* • Malpighia emarginata • Rubus glaucus • Ugni molinae • Vaccinium floribundum

INTRODUCTION

Berries and their derived products have shown a positive impact on several chronic conditions, including obesity, cancer, and cardiovascular and neurodegenerative diseases.[1,2] Like other fruits, berries contain micro- and macronutrients such as vitamins, minerals, and fiber; however, their biological properties have been largely attributed to their high levels of various phenolic compounds, as well as the interactive synergies among their natural phytochemical components.[3,4] The health-related properties and chemical composition of berries commonly found in North America and Europe have been widely explored, whereas those native to South America have been given little attention. However, international interest in the berries of this region has increased in recent years mainly because of their potential health benefits and increasing consumer interest for novel exotic fruit selections in the market place. This article reviews the chemistry, biological activities, and commercialization of fruit-bearing plants from South America, specifically *Aristotelia chilensis*, *Euterpe oleracea*, *Malpighia emarginata*, *Ugni molinae*, *Fragaria chiloensis*, *Rubus glaucus*, *Rubus adenotrichus*, and *Vaccinium floribundum.*

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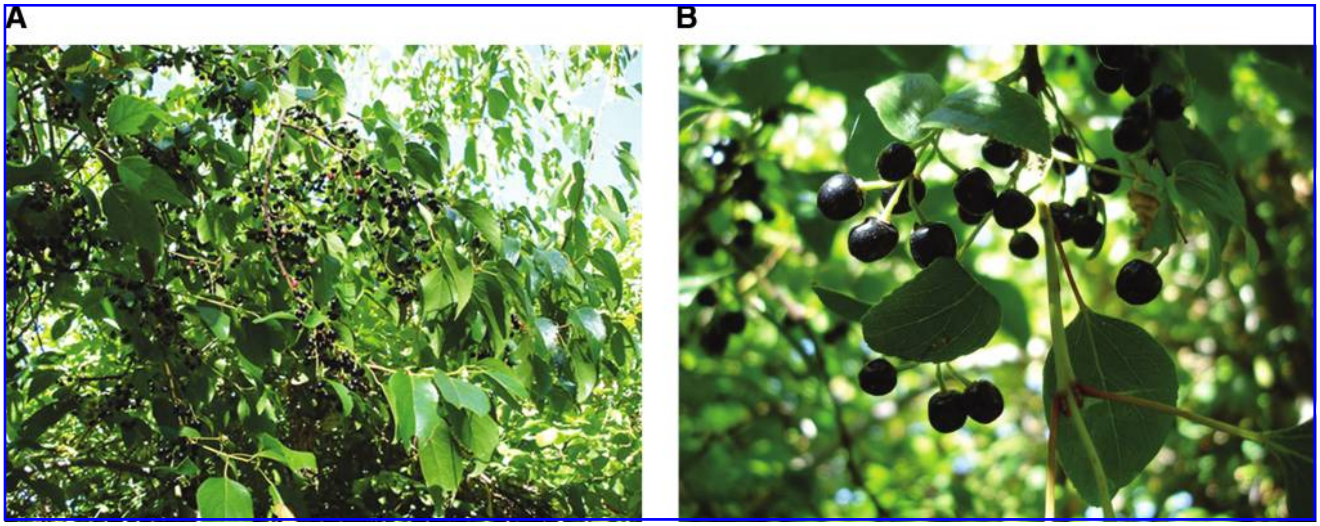
ARISTOTELIA CHILENSIS

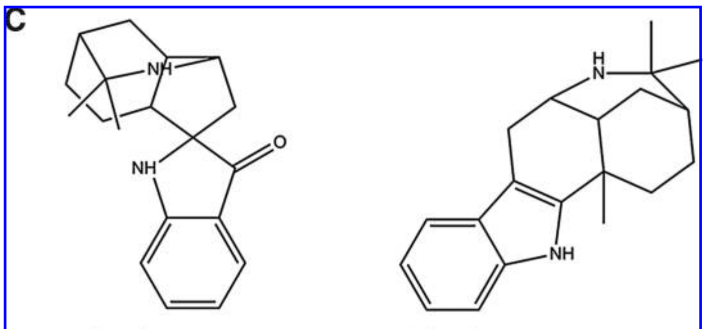
Ethnobotany and botanical description

A. chilensis is a dioecious fruit-bearing shrub that thrives in the temperate forests of central to southern Chile and western Argentina (Fig. 1A).[5–8] It belongs to the Elaeocarpaceae family and is commonly known as "maqui," "clon," "queldron," and "koelon."[9] It is an evergreen shrub that may grow in "macales," or dense thickets, reaching 3–5 m in height.[7] Maqui typically grows in moist, well-drained soils in either high or low light environments, but has consistently shown higher survival rates with exposure to high light.[10] *A. chilensis* yields a small edible purple/black berry averaging 5 mm in diameter and typically three or four seeds (Fig. 1B).[7] This fruit contains significantly more pulp than other berries of this region,[11] and its flavor is often described as "astringent but fresh."[8] The leaves and fruits of *A. chilensis* have been used in folk medicine to treat a variety of ailments, including sore throat, kidney pains, ulcers, fever, hemorrhoids, inflammation, diarrhea, lesions, migraines, and scars.[6,7,12]

Phytochemistry

There are several reports concerning the chemical composition of *A. chilensis* (Table 1) that have indicated the presence of indole and quinoline alkaloids within leaf tissue (Fig. 1C)[17–19] and high levels of polyphenols in the berry.[20,21] Among polyphenols, the maqui berry has been shown to have a relatively high anthocyanin content





Aristoteline Aristotelone

FIG. 1. Photographs showing (**A**) the shrub and (**B**) the berries and (**C**) the chemical structures of two indole alkaloids present in the leaves of *A. chilensis.* (**A**) and (**B**) reproduced courtesy of Guillermo Moreno Crisóstomo (http://www.nublenaturaleza.cl/articulos/flora/arboes/el-maqui/). Color images available online at www.liebertonline.com/jmf.

(137.6 ± 0.4 mg/100 g fresh weight [FW]), and analysis of anthocyanidin constituents has shown that delphinidin-3-sambubioside-5-glucoside is the principal anthocyanin, corresponding to 34% of total anthocyanins.[16]

Biological activities and health effects

The berries and leaves of *A. chilensis* have demonstrated diverse biological properties that are mainly attributed to their rich phenolic content and antioxidant capacity.[20,21] For instance, the maqui berry juice inhibits low-density lipoprotein oxidation and protects human endothelial cells against intracellular oxidative stress, thus suggesting possible anti-atherogenic properties.[20] Methanol extracts of mature maqui berries have also exhibited a protective effect against acute isochemia/reperfusion when studies were performed *in vivo* in rat hearts. The fruit extracts likely prevented these harmful effects by reducing lipid oxidation and the concentration of thiobarbituric acid-reactive substances.[21] Extracts from the maqui leaves have also shown potential nematicidal[22] and antiviral[23] activities. Furthermore, aqueous extracts of *A. chilensis* leaves can induce alteration in human erythrocyte morphology by interacting with the membrane's outer phospholipid monolayer. These results suggest that the molecular mechanism of action of *A. chilensis* leaf extracts can be attributed to functional perturbation of cell membrane lipid bilayers (Table 2).[9] In addition, the *A. chilensis* berries exhibit relatively high mineral levels: 100 g of maqui berries yields 27% of the recommended daily allowance (RDA) for calcium 28% of the RDA for potassium, and 70% of the RDA for iron; in contrast, the plant exhibits low sodium levels. Thus,

Table 1. Phytochemicals Detected in Leaves and Fruits of the Maqui Berry (*A. chilensis*)

Phytochemical constituent	*Plant part used*	*Reference*
Alkaloids	Leaves	
8-Oxo-9-dehydrohobartine		13
8-Oxo-9-dehydromakomakine		13
Aristone		14
Aristotelinine		15
Aristotelone		6
Aristoteline		6
Phenolics	Fruit	16
Delphinidin-3-sambubioside-5-glucoside		
Delphinidin-3,5-diglucoside		
Cyanidin-3-sambubioside-5-glucoside		
Cyanidin-3-sambubioside-5-glucoside		
Cyanidin-3,5-diglucoside		
Delphinidin-3-sambubioside		
Delphinidin-3-glucoside		
Cyanidin-3-sambubioside		
Cyanidin-3-glucoside		

TABLE 2. BIOLOGICAL ACTIVITIES OF FRUITS AND LEAVES OF MAQUI BERRY (*A. CHILENSIS*)

Part used	*Biological property*	*Model*	*Dose/effectiveness*	*Reference*
Fruit	Cardioprotective effect	Male Wistar rats	Single-dose methanol extract (10 mg/kg)	21
	Antioxidant activity	Human umbilical vein cells	10 μM GAE juice	20
		Human LDL from lipidemic blood donors	1 μM GAE juice	20
Leaves	Nematicidal activity	*Xiphinema americanum sensu lato*	25% 1:4 (wt/vol) aqueous extract	22
	Antiviral activity	*Herpesvirus hominis* type 2	$IC_{50} = 40\ \mu g/mL$ hydroalcoholic extract	23
	Alteration of human erythrocyte morphology	Human erythrocytes	1 mM GAE aqueous extract	9

IC_{50}, 50% inhibitory concentration; LDL, low-density lipoprotein; GAE, gallic acid equivalent.

A. chilensis shows potential for use in dietary supplements or functional foods.[9]

Commercial use

A. chilensis is a widespread plant that is regionally collected and typically consumed fresh or used to make jam, tea, wine, and juice.[11,21] In addition, it is commonly used as a natural dye because of its high content of anthocyanin pigments.[7] Recently, the use of this plant has outgrown its traditional borders, reaching new areas of commercialization. For instance, a topical formulation containing maqui berry extracts, with a high oxygen radical absorbance capacity, has been developed and patented for the prevention and treatment of skin damage, particularly damage resulting from aging and sun exposure.[24] Furthermore, functional beverages and dietary supplements containing maqui berry extracts and featuring a patent-pending Maqui Superberry™ (Novelle International, Inc., Bradenton, FL, USA; http://www.novellinternational.com) are available in the market.[25]

EUTERPE OLERACEA

Ethnobotany and botanical description

E. oleracea, more commonly referred to as açaí, is a fruit-bearing monoecious palm that flourishes in the inundated soils of the Amazon basin as well as other regions of Central and South America (Fig. 2A).[26–28] *E. oleracea* typically thrives in warm, humid climates with slightly acidic (pH 4–6) wet soils.[29] The palms exhibit gray trunks 20–30 m in height[28] and have multiple stalks that bear between three and eight fruit clusters, each of which may contain up to 900 berries (Fig. 2B).[30]

Açaí fruit (also known as palm berries) is round and dark purple when mature with an average diameter of 2 cm. The berries are described as having a nutty flavor with lingering metallic undertones and a creamy, yet oily texture.[28] Two varieties of the berry exist and are regionally known in Brazil as "açaí preto" and "açaí branco." "Açaí preto" exhibits a dark purple to black color, whereas "açaí branco" is olive green and yields a creamier juice.[31]

Palm berries have been established as a regional staple in South America, with a rich history of traditional use among indigenous and rural inhabitants.[31] To this day, the açaí berry is fundamental to some indigenous groups, comprising up to 40% of their diets.[32,33] Similarly, some rural inhabitants consume açaí berry juice with nearly every meal, relying upon it for adequate caloric intake.[31] In addition, many indigenous tribes attribute healing powers to different parts of the plant. Palm berries and roots are used to cure gastrointestinal problems, whereas its leaves are crushed and used to aid blood clotting in wounds, and its sap may be used as an astringent.[34]

Phytochemistry

The phytochemical composition of the açaí fruit has been well characterized, revealing a variety of phenolic acids, anthocyanins, proanthocyanidins, and other flavonoids. Among the anthocyanins, cyanidin-3-*O*-rutinoside and cyanidin-*O*-glucoside have been reported as the major constituents (Fig. 2C).[27,35,36] In addition, lignans have been reported as constituents of this fruit and were found to be representative of the aryltetrahydronaphthalene, dihydrobenzofuran, furofuran, 8-*O*-4'-neolignan, and tetrahydrofuran structural types.[37] The polyphenolic compounds present in the seed of açaí's fruit have also been reported (Table 3).[40]

Biological activities and health effects

Açaí has been shown to possess anti-inflammatory activity *in vitro*. Specifically, this palm berry inhibited the activity of cyclooxygenase (COX)-1 and -2 *in vitro*, with greater efficacy against COX-1.[35] Açaí extracts also inhibited lipopolysaccharide- and interferon-γ-induced nitric oxide production by reducing the expression of inducible nitric oxide synthase expression.[41] Consumption of MonaVie Active™ (South Jordan, UT, USA), a juice blend containing açaí as the main component, has demonstrated *in vivo* anti-inflammatory and antioxidant properties.[42] In addition, açaí skin and seed extracts induced an endothelium-dependent vasodilator effect in rats, which may suggest possible cardioprotective properties.[43] This berry has also shown to possess anticancer activity *in vitro*; various açaí phenolic extracts have exhibited the ability to reduce proliferation of leukemia[44] and human colon adecarcinoma cells.[45] Additionally, a clinical trial demonstrated the bioavailability of anthocyanins from açaí and an increase in the antioxidant capacity of

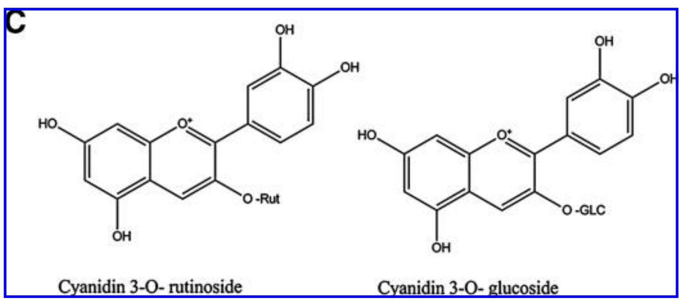


FIG. 2. Photographs of (**A**) the palm and (**B**) the berries and (**C**) the chemical structures of the main anthocyanins present in the fruit of *E. oleracea*. (**A**) reproduced courtesy of Howard G. Charing (http://www.flickr.com/search/?=acai&w=9671795%40N04); (**B**) reproduced courtesy of Ronaldo Salame (http://ronaldosalame-fotos.blogspot.com/2008/11/aa_09.html). Color images available online at www.liebertonline.com/jmf.

human plasma, after the consumption of açaí juice and pulp in moderate amounts.[44] Lignans isolated from this fruit have demonstrated bioactive properties, specifically antioxidant and cytoprotective activities (Table 4).[37] Furthermore, açaí has been found to contain some vitamins (thiamin, riboflavin, niacin, vitamin E, vitamin C) and minerals (iron, potassium, phosphorus, calcium) and high levels of oleic acid, β-sitosterol, and dietary fiber, further supporting its potential as a medicinal and functional food.[35]

Commercial use

E. oleracea is economically valuable because of the multifaceted uses that exist for multiple parts of the plant. Palm berries are incorporated into a variety of foods, including juices, smoothies, popsicles, ice cream, soda, and pastries. The fruit is also commonly mixed with cassava flour, rice, or tapioca and is frequently used in seafood dishes.[28,47] Recently, the commercial borders of this berry have expanded greatly, and currently companies are devel-

Table 3. Phytochemicals Detected in Seeds and Fruits of Açaí (*E. oleracea*)

Phytochemical constituent (phenolics)	*Plant part used*	*References*
Catechin, quercetin-rutinoside, peonidin-rutinoside, protocatechuic acid, procyanidin dimer, procyanidin trimer, procyanidin tetramer	Fruit	38
Cyanidin-3-glucoside, pelargonidin-3-glucoside, ferulic acid, *p*-hydroxybenzoic acid, gallic acid, ellagic acid, vanillic acid, *p*-coumaric acid	Fruit	39
Homoorientin, orientin, isovitexin, cyanidin-3-*O*-glucoside, cyanidin-3-*O*-rutinoside	Fruit	27
Protocatechuic acid, procyanidin dimer, procyanidin trimer, procyanidin tetramer, procyanidin pentamer, procyanidin pentamer, epicatechin	Seed	40

TABLE 4. BIOLOGICAL ACTIVITIES OF FRUITS AND LEAVES OF AÇAÍ (*E. OLERACEA*)

Biological property of fruit	*Model*	*Dose/effectiveness*	*Reference*
Cytoprotective activity	MCF-7 cells, breast cancer	20 μg/mL	37
Antioxidant activity	Human trial	7 mL/kg of body weight açaí pulp or juice	44
Anticarcinogenic activity	HT-29 adenocarcinoma cells	0–12 μg of GAE/mL	45
Antioxidant activity	Erythrocytes	0.016–10 g/L juice blend	42
	Human trial	120 mL of juice blend	42
Anti-inflammatory activity	Polymorphonuclear cells	1 g/mL juice blend	42
	Human trial	120 mL of juice blend	42
Vasodilator effect	Male Wistar rats	Skin extract (ED_{50} = 317.8 μg; CI = 246.2 to 410.2)	43
		Stone extract (ED_{50} = 1.1 μg; CI = 0.99 to 1.26)	43
Anticarcinogenic activity	HL-60 leukemia cells	0.17–10.7 μM total soluble phenolics of extracts	46
COX-1 and COX-2 inhibitor	COX-1 and COX-2 enzymes	IC_{50} COX-1 = 6.96 mg/mL	35
		IC_{50} COX-2 = 12.50 mg/mL of acetone extract	35

CI, confidence interval; ED_{50}, 50% effective dose; IC_{50}, 50% inhibitory concentration; GAE, gallic acid equivalent.

oping açaí products in novel forms such as tablets, juice, smoothies, and instant drink powders. In addition, açaí stalks may be harvested as palmito or as hearts of palm, whereas seeds may be ground up and used as livestock feed.[28,48] Furthermore, the anthocyanins present in *E. oleracea* have been used successfully as a functional food pigment[49] and as an alternative oral contrast agent in magnetic resonance imaging of the gastrointestinal system.[50] International interest is generally targeted towards the ‘‘açaí preto’’ variant because it is more commonly available.[33]

MALPIGHIA EMARGINATA

Ethnobotany and botanical description

M. emarginata, most commonly referred to as ‘‘acerola,’’ is a widespread shrub of the Malpighiaceae family (Fig. 3A).[51–53] It may also be referred to as ‘‘chercese,’’ ‘‘Barbados cherry,’’ ‘‘French cherry,’’ ‘‘garden cherry,’’ or ‘‘West Indian cherry.’’[54,55] Acerola is thought to be native to the Caribbean Islands, Central America, or northern South America. Currently, it is cultivated in Puerto Rico, southern Florida, Hawaii, Barbados, the Windward Islands, Okinawa, Taiwan, the east Caribbean, and Brazil, which is the leading producer. *M. emarginata* thrives in warm, tropical climates close to sea level but has shown successful growth at elevations up to 150 m. In addition to this, it may grow at a variety of soil pHs, ranging from slightly acidic to slightly alkaline.[55,56]

M. emarginata is a fruit-bearing shrub that averages 4.6 m in height and exhibits white to pink flowers. Its fruit experiences biphasic growth and develops as a three-carpellate drupaceous berry; otherwise, it looks like the common cherry (Fig. 3B). Each drupe ranges from 1 to 4 cm in diameter and weighs between 3 and 10 g.[55,56] Acerola cherries may exhibit a variety of colors, depending upon maturity and origin, spanning from green to orange-red to dark reddish-purple.[57] The fruit bears a thin, delicate skin that is susceptible to bruising and deterioration after harvest.[58] Acerola cherries are a staple at local marketplaces. They are typically sold for raw consumption but may also be used to make hot and cold pressed juices, compotes, and jellies. *M. emarginata* is also sold for medicinal purposes, and properties that have been attributed to it include curing the common cold and the flu, as well as pulmonary, liver, and gallbladder ailments.[59]

Phytochemistry

The fruit of *M. emarginata* contains a wide variety of flavonoids, phenolic acids, and carotenoids. The main flavonoid subgroups present in this fruit are anthocyanins, proanthocyanins, flavonols, and catechins. The anthocyanin content can vary between 37 and 597.4 mg/kg[60] and consists mainly of cyanidin-3-α-*O*-rhamnoside (76–78%) and pelargonidin-3-α-rhamnoside (12–15%),[61,62] but malvidin-3,5-diglucoside has also been reported.[63] This fruit also contains flavonols (70–185 mg/kg)[64] such as quercitrin, hyperoside, and kaemperol glycosides.[53] Among the phenolic acids, caffeic acid, *p*-coumaric acid, and ferulic acid have been reported.[62] Recently, a novel flavonoid, leucocyanidin-3-*O*-β-D-glucoside, was isolated from mature green acerola puree and named aceronidin (Fig. 3C).[53] In addition, much attention has been paid to carotenoid content in acerola fruit and its derived products. Acerola fruits contain between 0.32 and 40.6 mg of total carotenoids, depending on the stage of maturity, genotype, and harvest season. The carotenoid pigments increase during the mature state[65]; in ripe fruit, four major carotenoids have been identified (β-carotene, β-cryptoxanthin, lutein, and violaxanthin) as well as several minor carotenoids (neoxanthin, antheraxanthin, neochrome, luteoxanthin, auroxanthin, β-cryptoxanthin-5,6-epoxide, β-cryptoxanthin-5,8-epoxide, *cis*-β-carotene, and *cis*-lutein)[66] (Table 5). The volatile components of the mature fruit have also been investigated, from which furfural, hexadecanoic acid, 3-methyl-3-buthenol, and limonene were the major constituents[67]; however, these vary depending on the stage of maturity.[58] In addition to its phytochemical content, acerola possess high ascorbic acid levels, ranging from 1,000 to 4,500 mg/100 g of pulp. Ascorbic acid is highest in unripe green fruit and decreases in concentration as the fruit ripens.[66,68] Although the type

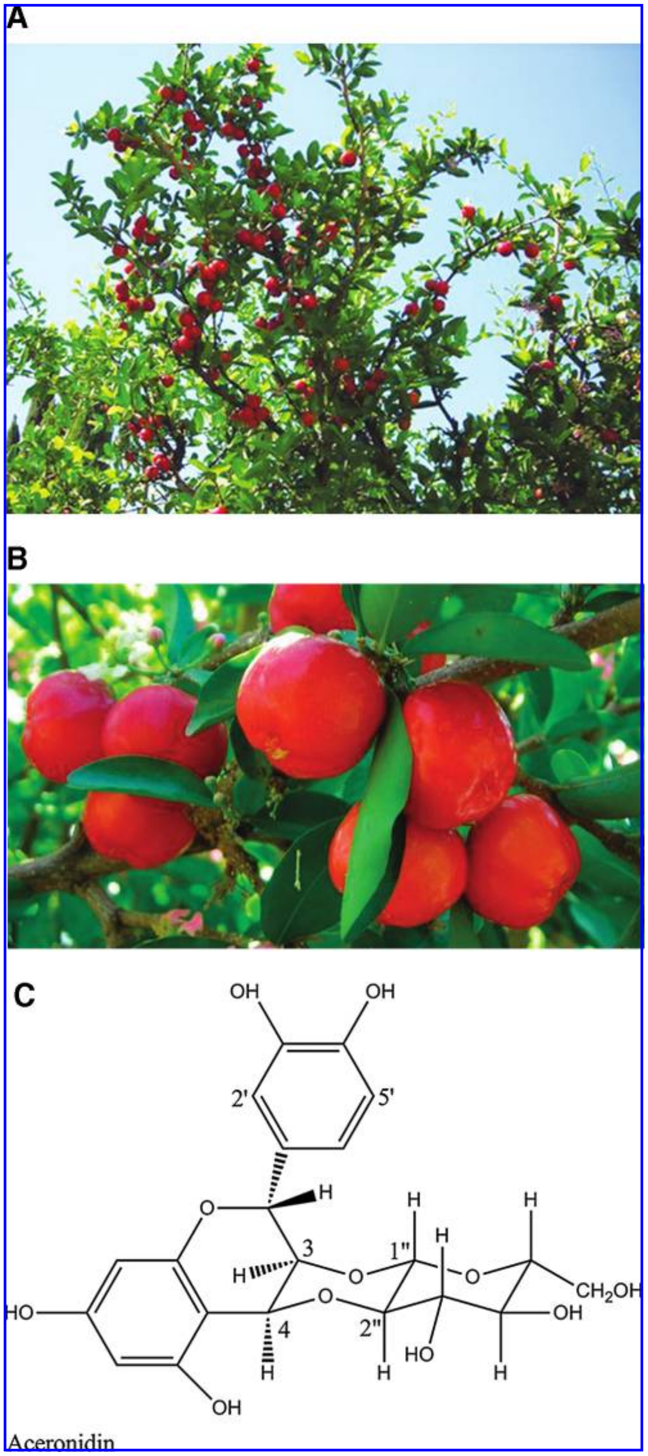


FIG. 3. Photographs showing (**A**) the shrub and (**B**) the berries and (**C**) the chemical structure of the novel flavonoid aceronidin present in the fruit of *M. emarginata*. (**A**) and (**B**) reproduced courtesy of Papaya Tree Nursery (http://www.papayatreenursery.com/gallery/main.php?g2_itemId = 972). Color images available online at www.liebertonline.com/jmf.

Table 5. Phytochemicals Detected in Fruits of Acerola (*M. emarginata*)

Phytochemical constituent	*Reference*
Carotenoids	
Antheraxanthin, auroxanthin, lutein, luteoxanthin, neochrome, neochrome isomer, neoxanthin isomer, mutatoxanthin, violaxanthin, violaxanthin isomer, neoxanthin, β-cryptoxanthin-5,6-epoxide, β-carotene, β-cryptoxanthin, β-cryptoxanthin-5,8-epoxide, *cis*-β-carotene, *cis*-lutein	66
Phenolics	
Cyanidin-3-α-*O*-rhamnoside, pelargonidin-3-α-*O*-rhamnoside, quercetin-3-α-O-rhamnoside	62
Leucocyanidin-3-*O*-β-D-glucoside	53
Caffeic acid, *p*-coumaric acid, ferulic acid, quercetin, kaempferol	63

of compounds present in acerola remain relatively constant, concentrations will vary depending on the climatic conditions, ecotype, stage of maturation, processing, and storage.[69]

Biological activities and health effects

The fruit of *M. emarginata* has received much interest in past years due to potential health benefits associated with its antioxidant capacity and high levels of ascorbic acid, carotenoids, and polyphenols. Acerola's rich antioxidant capacity is mainly due to its content in vitamin C and polyphenolic content[70]; among the latter, phenolic acids appear to be the main contributors to the antioxidant capacity of this fruit.[64] A crude polyphenol extract from acerola has been shown to lighten ultraviolet light-irradiated skin pigmentation *in vivo*; this effect was partially attributed to the inhibition of melanogenesis through the inhibition of tyrosine activity in melanocytes.[71] In addition, a crude acerola polyphenol fraction had a preventive effect against hyperglycemia in the postprandial state; the mechanism for this effect may involve the suppression of the intestinal glucose transport and the inhibition of α-glucosidase. However, the therapeutic effects of this acerola fraction on hyperglycemic mice were insignificant.[72] Aceronidin, the novel flavonoid present in acerola, demonstrated antioxidant activity as well as inhibitory activity against both α-glucosidase and α-amylase.[53] Anti-inflammatory activity has also been seen in acerola. Fruit extracts have been shown to inhibit nitric oxide production in mouse macrophages because of inhibition of inducible nitric oxide synthase expression and radical scavenging.[73] Furthermore, an acerola extract pretreatment inhibited the initiation of lung carcinogenesis in mice, showing both tumor-specific cytotoxic activity and multidrug resistance reversal activity,[74] suggesting the possible applications for cancer therapy. In addition, acerola also exhibits and antifungal properties.[75] The toxic effect of the polyphenol extract of acerola was evaluated in rats via oral toxicological assays, and these showed no significant risks associated with the oral administration of this extract (Table 6).[77]

Commercial use

M. emarginata is of commercial interest mainly due to its rich ascorbic acid content. Vitamin C extracts have been derived from this berry for use in dietary supplements, although more research on the bioavailability of acerola's ascorbic acid is needed.[78,79] A recent study developed an acerola ice cream suitable for the delivery of vitamin C and *Bifidobacterium* strains, while maintaining excellent viability and acceptable sensory characteristics.[80] These cherries have been incorporated into commercial fruit juices and energy drinks and are an increasingly attractive additive due to current interest in developing products with health-related properties.[61,81] Furthermore, at immature stages acerola can be used as a pectin source in confections or as an enriched source of dietary fiber.[82]

UGNI MOLINAE

Ethnobotany and botanical description

U. molinae, also known as "murta," "murtilla," "uñi," "myrtle berry," "Chilean cranberry," or "Chilean guava," is a plant native to Chile, western Argentina, and certain regions of Bolivia. It is a wild shrub ($\sim$1.8 m tall) of the Myrtaceae family that typically dwells near the coastal and pre-Andean mountains of South America; however, it can also thrive in subtropical regions, such as the Juan Fernández Islands (Fig. 4A).[83–86] *U. molinae* also readily sprouts in relatively desolated areas, such as sites of old lava flows, indicating that it is versatile.[87,88] Murta is a well-known regional plant that bears aromatic red globular fruit. The berries typically possess a diameter of 0.7–1.3 cm and weigh between 0.25 and 0.40 g (Fig. 4B).[86,87] Murta fruit is said to combine the sweetness of a strawberry with the pungency of a guava and the texture of a dried blueberry.[89] Murta's leaves have been used in Chilean folk medicine to treat conditions such as diarrhea, dysentery, and urinary tract pain.[90] It is also used for its astringent and stimulant properties.[86]

Phytochemistry

The phytochemical composition of *U. molinae* includes a wide variety of polyphenols in its leaves and fruits[91,92] and pentacyclic triterpene acids in its leaves (alphotolic, corosolic, and asiatic acid) (Fig. 4C).[85,91,92] It has been shown that the chemical composition of Murta can vary depending on the climatic conditions at which the plant is subjected to during its growth: an extreme climate is the condition that promotes polyphenol content in its leaves.[92] In addition, 24 volatile compounds of the murta fruit aroma have been elucidated, of which methyl 2-methyl butanoate, ethyl butanoate, ethyl 2-methyl butanoate, methyl hexanoate, ethyl hexanoate, methylbenzoate, and ethyl benzoate were the major components (Table 7).[94]

Biological activities and health effects

U. molinae leaf extracts have shown a strong topical anti-inflammatory activity in mice, and this is principally due to the presence of several pentacyclic triterpene acids, including the 2-α-hydroxy derivatives alphitolic, asiatic, and corosolic acids.[85] Furthermore, murta leaf extracts have shown analgesic activity in thermal and chemical pain mice models *in vivo*[95] and also protective antioxidant properties in human erythrocytes exposed to the oxidative stress of hypochlorous acid.[96] Moreover, the consumption of the infusion of murta's leaves has shown to increase the antioxidant capacity of human serum.[97] The antioxidant activity and other properties that murta leaf extracts have been shown to possess are possibly related to their capacity to locate into the membrane bilayer, restrict its fluidity, hinder the diffusion of free radicals, and protect alteration of human erythrocyte.[96,98] In addition, the aqueous extracts from murta leaf have an inhibitory effect against the growth of *Pseudomonas aeruginosa*, *Klebsiella pneumoniae*, and *Staphylococcus aureus* with few deleterious effects on beneficial probiotic bacteria.[92] Murta dry leaf extracts have also shown a nematicidal effect against the rot-knot nematode, *Meloidogyne hapla* (Table 8).[99]

Commercial use

Use of *U. molinae* is primarily restricted to South America, and this plant does not currently exhibit widespread commercial use. Typically, it is gathered and sold in local marketplaces for raw consumption and small-scale processing. Juices, jams, jellies, and liquors are prepared from the berries, whereas a tea can be made from

TABLE 6. BIOLOGICAL ACTIVITIES OF FRUITS AND LEAVES OF ACEROLA (*M. EMARGINATA*)

Biological property of fruit	*Model*	*Dose*	*Reference*
Skin lightening effect	5-week-old female brownish guinea pigs	Orally administered 400 mg/kg of body weight/day	71
Antihyperglycemic effect	Caco-2 cells	IC_{50} = 0.2 mg/mL C-AP	72
	Mice	Single dose 43.75 mg/mL C-AP	72
Tumor-specific cytotoxic activity	HTLV1, HSG cells	Hexane fraction IC_{50} = 87 μg/mL	76
Reversal multidrug resistance effect	L5178 mouse T cells lymphoma cell line	4–10 μg/mL hexane-acetone and 10 μg/mL acetone fraction	76

C-AP, a crude acerola polyphenol fraction; IC_{50}, 50% inhibitory concentration.

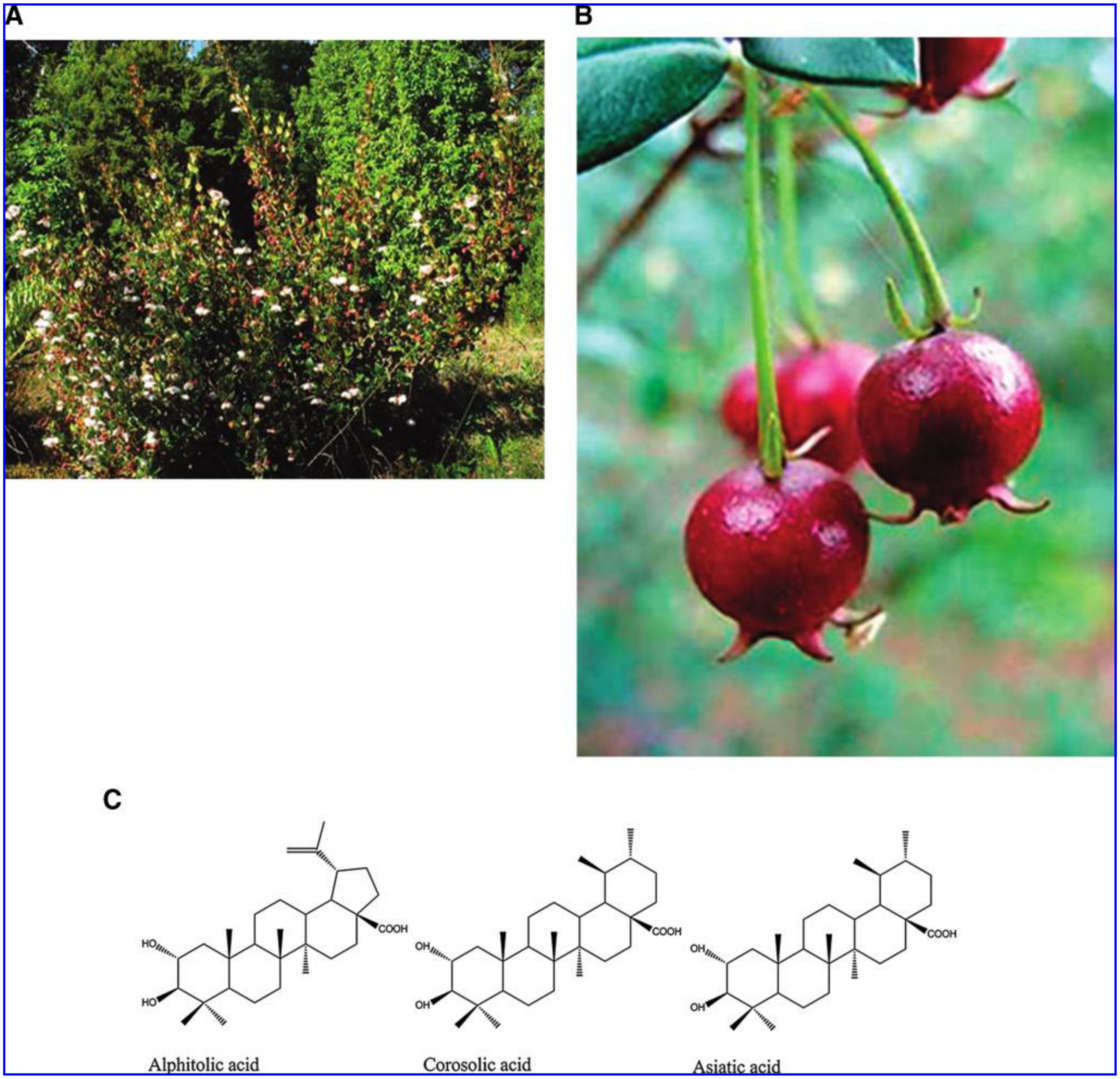


FIG. 4. Photographs showing (**A**) the shrub and (**B**) the berries and (**C**) the chemical structures of pentacyclic triterpene acids present in the leaves of *U. molinae*. (**A**) reproduced courtesy of Michail Below (http://www.chileflora.com/Florachilena/FloraEnglish/HighResPages/EH0291A.htm); (**B**) reproduced courtesy of Marcia Andrea Avello (http://www.scielo.cl/scielo.php?pid = s0718-04622006000200010&script = sci_arttext). Color images available online at www.liebertonline.com/jmf.

the leaves, and a coffee-like beverage may be derived from the seeds.[86,88] Although this plant and its derived products are primarily sold locally, it has shown promise for future commercial growth. Murta leaves have sparked interest in the cosmetic industry because of their antioxidant, phytoestrogenic, and polyphenolic content, which may help combat wrinkles and other signs of premature aging.[91] In addition, *U. molinae* may also be used in food processing as an environmentally friendly preservative. Recent studies have incorporated murta leaf extracts into gelatin-based edible films for a variety of foods, protecting food products from dehydration and from deterioration caused by ultraviolet light exposure. Gelatin-based films containing murta leaf extracts have shown potential for sustaining the quality and shelf life of certain foods, when compared to typical gelatin films. When incorporated into fish-based gelatin matrices, murta leaves have been shown to decrease the transparency of the films, thereby increasing the absorbance levels of ultraviolet light and impeding ultraviolet light-induced lipid oxida-

Table 7. Phytochemicals Detected in Leaves and Fruits of Murta (*U. molinae*)

Phytochemical constituent	*Plant part used*	*Reference*
Phenolics		
Epicatechin, myricetin dirhamnoside, myricetin glucoside, myricetin rhamnoside, myricetin xyloside, quercetin glucoside, kaempferol glucoside, quercetin rhamnoside, quercetin dirhamnoside, quercetin xyloside	Leaves	91
Flavan-3-ol (epi)gallocatechin, flavan-3-ol (epi)catechin, polymeric flavan-3-ol (epi)catechin	Leaves	92
Myricetin glucoside, quercetin dirhamnoside, quercetin glucoside, quercetin glucuronide	Fruits	92
Triterpenoids		
Alphitolic acid, asiatic acid, betulinic acid, corosolic acid, oleanolic acid, ursolic acid	Leaves	85
Volatile compounds		
Methyl butanoate, ethyl 2-methyl propanoate, ethyl 2-methyl butanoate, ethyl butanoate, *n*-butyl acetate, methyl pentanoate, methyl (2*E*)-but-2-enoate, propan-2-yl butanoate, ethyl 2-methyl butanoate, ethyl pentanoate, methyl hexanoate, benzaldehyde α-pinene, ethyl hexanoate, hexyl acetate 1,8-cineole, D-limonene, methyl benzoate, methyl octanoate, ethyl benzoate, ethyl octanoate	Fruits	93

tion. The high polyphenol content and antioxidant capacity of murta leaves also hinder rancidity of foods and lipid oxidation.[93,100] Murta leaves have also been used as a cross-linking agent in carboxymethylcellulose-based films. Their incorporation has been shown to decrease the water permeability of films while achieving selective gas permeability; this mechanism is attributed to the high polyphenol content of the leaves.[101] Thus, *U. molinae* shows great potential as a natural preservative for a variety of food products ranging from meats to fresh fruits and vegetables.

OTHER BERRIES

Studies concerning berries from South America have mainly focused on the species described above, with limited information about the chemistry and biological activities of other berry-producing species including *R. glaucus*, *R. adenotrichus*, *F. chiloensis*, and *V. floribundum* (Table 9). *R. glaucus* is a climbing perennial shrub belonging to the Rosaceae family and is native to the Andes in northern South America. The berry is appreciated for its attractive dark-red color, juiciness, and flavor in comparison to most cultivated blackberries. *R. adenotrichus* is also a perennial shrub belonging to the Rosaceae family. This species is found mainly in Mexico and Ecuador and is known as "Mora común."[107] The phenolic compounds of *R. glaucus* and *R. adenotrichus* have been reported, showing that ellagitannins are the predominant compounds in both species, mainly sangiin H-6 and lambertianin. The major flavonol glycosides and hydroxycinnamic acid were quercetin glycosides and *p*-coumaric acid, respectively. These two species differ in their anthocyanin profile as well as in the presence or absence of kaempferol glucosides. As for anthocyanins, cyanidin-3-glucoside and cyanidin-3-malonyl glucoside were detected in *R. adenotrichus*, whereas cyanidin-3-glucoside and cyanidin-3-rutinoside were found in *R. glaucus*.[103] In a more recent study, cyanidin-3-sambubioside, cyanidin-3-xylorutinoside, pelargonidin-3-

Table 8. Biological Activities of Fruits and Leaves of Murta (*U. molinae*)

Part used	*Biological property*	*Model*	*Dose*	*Reference*
Leaves and fruit	Antimicrobial activity	*P. aeruginosa*, *K. pneumoniae*, *S. aureus*	90 μL of 50:50 water:ethanol extract	92
Leaves	Antiparasitic activity	*M. hapla*	1% (wt/wt) dry leaves in sandy soil substrate	99
	Analgesic effect	CF-1 male mice	Intraperitoneal administration: $ED_{50} = 1.37$ mg/kg methanol extract	95
			Oral administration: $ED_{50=}$ 199 mg/kg dichloromethane extract	95
			Topical administration: $ED_{50} = 2\%$ (wt/vol) dichloromethane extract	95
	Antioxidant activity	Erythrocytes	10 μ*M* GAE	96
	Topical anti-inflammatory activity	CF-1 male mice	1 mg of leaf extract per ear	85
	Alteration of human erythrocyte morphology	Human erythrocytes	1 m*M* GAE aqueous extract	98
	Antioxidant activity	Human trial	1% (wt/vol) dry leaf infusion consumed twice per day for 3 days	97

ED_{50}, 50% effective dose; GAE, gallic acid equivalent.

TABLE 9. PHYTOCHEMICALS DETECTED IN FRUITS OF OTHER BERRIES NATIVE TO SOUTH AMERICA

Species	*Phytochemical constituent*	*Reference*
R. glaucus	Pelargonidin-3-rutinoside, pelargonidin-3-glucoside, cyaniding-3-xylorutinoside	102
	Gallic acid, caffeoyl esters, *p*-coumaroyl esters, feruloyl esters, flavan-3-ols, (−)-epicatechin, ellagic acid pentosides, methylellagic acid pentoside, ellagic acid hexoside, ellagic acid derivative, quercetin glucoside-malonate, quercetin derivative, cyanidin-3-glucoside, cyanidin-3-rutinoside	103
R. adenotrichus	Gallic acid, galloyl esters, caffeoyl esters, *p*-coumaroyl esters, feruloyl esters, (−)-epicatechin, ellagic acid pentosides, methylellagic acid pentoside, ellagic acid hexoside, ellagic acid, quercetin, glucoside-malonate quercetin derivative, kaempferol glucoside, kaempferol glucuronide, cyanidin-3-glucoside, cyanidin-3-rutinoside, cyanidin-3-malonyl glucoside, lambertianin C	103
F. chiloensis	1-*O*-*E*-Cinnamoyl-*β*-D-rhamnopyranoside, 1-*O*-*E*-cinnamoyl-*α*-xylofuranosyl-(1-6)-*β*-D-glucopyranose, 1-*O*-*E*-cinnamoyl-*β*-D-xylopyranoside, cyanidin-3-*O*-*β*-D-glucopyranoside, ellagic acid, quercetin	104
	Ellagitannin, cyanidin-3-glucoside, pelargonidin-3-glucoside, cyanidin-malonyl-glucoside and pelargonidin-malonyl-glucoside, kaempferol coumaroyl-hexoside, deoxyhexoside, neochlorogenic acid, *p*-coumaric acid derivative, chlorogenic acid, caffeic/ferulic acid derivative, delphinidin hexoside, cyanidin	105
V. floribundum	Vanillic acid derivative, *p*-hydroxybenzoic acid derivative, gallic acid derivative, (−)-epicatechin, myricetin pentoside, quercetin hexoside, quercetin pentoside, quercetin hexoside, delphinidin pentoside, cyanidin hexoside, cyanidin pentoside, delphinidin aglycon, cyanidin aglycon	106

glucoside, and pelargonidin-3-rutinoside were also detected in *R. glaucus*, and the total anthocyanin content was reported to be 45 ± 7.07 mg/100 g FW; this species also contains significant amounts of ascorbic acid (10.1 mg/100 g FW) and total phenols (294 mg of gallic acid equivalents [GAE]/100 g FW) and exhibits high antioxidant activity.[102] In addition, the volatile constituents of *R. glaucus* have been reported from which 2-heptanol, ethyl benzoate, (*E*)-hex-2-enal, and 1-terpinen-4-ol were the major components.[108]

F. chiloensis, a trioecious strawberry of the Rosaceae family, is native to Southern Chile but can also be found in some other parts of South America.[109] The plant bears small white flowers and red or white berries (depending on the subspecies) that may be as large as a walnut.[110] Three E-cinnamic acid glycosides [1-*O*-*E*-cinnamoyl-*β*-D-xylopyranoside, 1-*O*-*E*-cinnamoyl-*β*-D-rhamnopyranoside, and 1-*O*-*E*-cinnamoyl-*α*-xylofuranosyl-(1-6)-*β*-D-glucopyranoside] and tryptophan were isolated from ripe fruits of *F. chiloensis*.[104] The anthocyanin profile of this fruit has been reported and includes cyanidin-3-glucoside, pelargonidin-3-glucoside, cyanidin-malonyl-glucoside, and pelargonidin-malonyl-glucoside as the main constituents; this berry also exhibits high levels of free ellagic acid.[105]

V. floribundum is a deciduous, spreading shrub that belongs to the Ericaceae family (Fig. 5A).[111] It bears cylindrical pink flowers and round blue to nearly black edible berries (Fig. 5B). This species is native to Ecuador and Peru but is also found in other countries in South and Central America.[112] *V. floribundum* berries are widely consumed in Ecuador as the fresh fruit or as processed products. Local communities also have used this plant to treat various medical conditions such as diabetes and inflammation.[113] The chemical composition and the phenolic profile of *V. floribundum* have been reported, revealing predominantly quercetin, hydroxycinnamic acids, and cyanidin-3-glucosides. Anthocyanins were shown to account for ~67% (345 mg of cyanidin/100 g FW) of the total phenolic compounds, with cyanidin derivatives being the major components (~89%). Among the hydroxycinnamic acids, chlorogenic and neochlorogenic together with caffeic and ferrulic acids were the predominant components. In addition, the total soluble phenolic content and the antioxidant capacity were reported as 882 mg of GAE/100 g FW and 1,200 mg of Trolox equivalents/100 g FW, respectively.[106] A commercial powder of *V. floribundum* that is produced and sold in Ecuador has been evaluated for its anthocyanin content. In accordance with the reported data two cyanidin derivatives (cyanidin hexoside and cyanidin pentoside) were found as the main components. The total anthocyanin content was shown to be lower than that of the fresh fruit (108.9 mg of cyanidin equivalent g/100 g of raw powder); this might be due to the processing conditions to which this fruit is exposed during the manufacture of the powder (authors' unpublished data).

FINAL REMARKS

The phytochemistry, health benefits, and commercial uses of several berry-producing plants native to South America have been reviewed. These plants possess a rich and diversified composition of bioactive compounds as well as health-promoting properties. Nevertheless, studies regarding their biological activities are limited, often lacking *in vivo* data. Future research is needed to better understand not only their efficacy but particularly their potential in regard to their use as supplements or as functional foods. The studies reviewed demonstrate the health potential of berries from South America; thus, greater attention should be given to native fruits from this region.

FIG. 5. Photographs showing (**A**) the shrub and (**B**) the berries of *V. floribundum.* Color images available online at www.liebertonline.com/jmf.

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