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Review Article

Andean berries from Ecuador: A review on Botany, Agronomy, Chemistry and Health Potential

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Abstract. Interest in exploring new and exotic types of berries has grown in recent years. Highly valued for its unique flavor, texture and color, recent researches have shown that Andean berries are an important source of bioactive compounds. This article provides botanical and agronomic descriptions and reviews the chemical and biological activities of two types of berries (*Physalis peruviana* L. and *Solanum betaceum* C.) and one commonly known as a berry, *Rubus glaucus* B. All highly consumed in Ecuador and enjoying great popularity in Andean traditional medicine. Although both traditional folk medicine and composition of these berries suggest significant health benefits, few studies to date have investigated these potentials.

Keywords: *Rubus glaucus* B., *Physalis peruviana* L. and *Solanum betaceum* C., Andean berries, anthocyanins, antioxidant properties, Health benefits.

1. Introduction

Eighty percent of the world population, especially in developing countries, uses plants as natural remedies and traditional medicine for facing primary needs of medical assistance [1], so Ecuador is not an exception. Ecuadorians have a sanitary system without a proper level of development that prevents a great part of the population from having access to formal medical care [2]. Nevertheless, since ancient times plants have played a relevant role in the development of Andean cultures, which is enhanced due to the high botanical diversity found in the Andes, including their use as therapeutic agents [3]. It is noteworthy that the country is one of the seventeen-megadiverse countries in the world [4, 5], being part of two biodiversity hotspots (Tumbes-Chocó-Magdalena and Tropical Andes) in only 283.560 km^2 [6, 7]. Its richness includes ecological zones of great value, from mangroves to tropical forest, rainforest, moors and snow-capped mountains. Thus, one third of all Ecuadorian plant species have been used by people [8] and nowadays the use of medicinal plants is still an important feature of traditional medicine, which is daily practiced in many indigenous communities (30% of the whole population belongs to different indigenous groups) and urban populations of all social classes [9, 10].

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Berries and their derived products have been shown to be exceptional functional products since they provide significant health benefits on several chronic conditions, including obesity, cancer, cardiovascular and neurodegenerative diseases because of their high content in phytochemicals, vitamins, minerals and fibre and the interactive synergies among their phytochemical components [11–14]. Recently, South American berries have been object of an increased interest mainly due to their potential health benefits and to the growing consumer interest in novel exotic fruits, particularly by international markets [12, 15]. Nevertheless, while health-related properties and chemical composition of berries commonly found in North America and Europe have been widely explored; those natives from South America need more information. Several scientific reports have pointed out the therapeutic potential of certain plants and foods from this area, for instance *Rubus glaucus* B., *Physalis peruviana* L. and *Solanum betaceum* C. are among the relevant ones [16–23].

The development of functional products derived from berry fruits represents another alternative for the exploitation of Ecuadorian resources, to supplement their nutritional value and to promote new export channels. This review presents current knowledge on chemistry, composition, and health benefits of two berries (*P. peruviana* L. and *S. betaceum* C.) and one commonly known as a berry, *Rubus glaucus* B.; which are mainly consumed in the Andean region of Ecuador.

2. Rubus glaucus Benth

2.1. Botanical aspects

R. glaucus is an evergreen shrub climber of the family *Rosaceae* and the genus *Rubus*, commonly called mora andina, mora de castilla or Andean blackberry in English-speaking countries. It is native to the northern part of the Andes, specifically the highland intertropical region, but it has also been introduced into many other tropical areas [21]. It is associated with blackberries of the subgenus *Rubus* and raspberries of the subgenus *Idaeobatus* as it shares morphological characters with both. Therefore, it is considered that *R. glaucus* is a fertile amphidiploid (2n = 21–84) product of hybridization between species of these two subgenera [24, 25]. It is a facultative apomictic species that produces sexual and asexual seeds (meiosis), so that sexual reproduction can occur in 10% of the population, thus maintaining genetic variability [26]. In Ecuador, the genetic variability of the species is poor and there are two well-formed groups [26]. Notably, the interesting gene pool of Andean blackberries has tried to be exploited for some years; thus, in the United States the Department of Agriculture (USDA) and other institutions have used *R. glaucus* germplasm to improve the characteristics of blackberries: fruit size, fruit quality, disease resistance and adaptation to climatic conditions of the southern United States [27].

The plant is a perennial bush-vine that reaches up to 2 meters tall and 3 meters long, whose trunk divides into several branches (5–10 or more) which are the stems [28]. The stems are cylindrical, long, erect, without villi, light green, red or dark brown and with prickly spines curved gradually tapering from base to tip [28, 29]. Sometimes the stems are covered by a kind of blue-white powder. The leaf consists of three lanceolate subcoriaceous leaflets rounded or slightly truncated at the base with acuminate apex and biserrate margin. The lower face of the leaves is whitish and villi. The inflorescences are lax and condensed, with 15 to 22 flowers and thorny pedicels without villi. The flowers are 18 to 22 mm in diameter, deltate sepals and ovate white petals. Although Andean blackberry is commonly referred as a berry; botanically do not correspond to this type of fruit. It is an aggregate fruit (seeds from different ovaries of a single flower) composed of many drupelets and has a size of about 1 to 2.5 cm long. It is from hairy to glabrous, red or black, from ovoid to rounded, with recurved sepals and with 70 to 100 drupeolas per well [28]. They are dark-red or purple when ripe and have a unique, heady, pleasant aroma and bittersweet flavor (Fig. 1A) [21].

2.2. Agronomic aspects

The Andean blackberries are produced from Mexico to Ecuador, being widely cultivated in Colombia, Costa-Rica and Ecuador where they grow all year round [30–32]. This is the only native species of *Rubus* grown commercially in the countries of Central and South America, where it is prized for its attractive dark-red color (Fig. 1A), juiciness

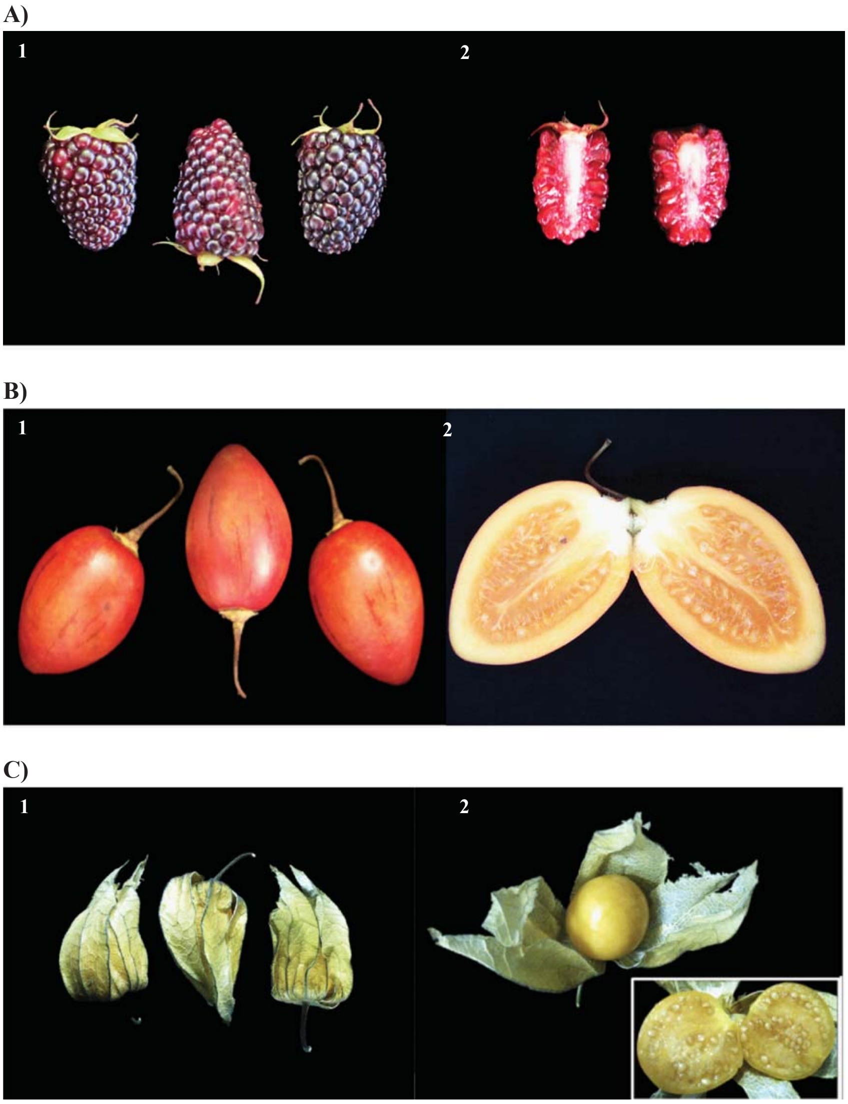

Fig. 1. Whole (1) and halved (2) *Rubus glaucus* (A), *Solanum betaceum* (B) and *Physalis peruviana* (C) fruits.

and flavour compared to other most popular blackberries [12]. In Ecuador, the Andean blackberry grows in the wild in isolation, scattered or in groups with other species [33] finding as optimal areas for production the Inter Andean valleys, mainly in the provinces of Tungurahua and Pichincha. Nonetheless, it has become an important production for the provinces of Carchi and Imbabura. There are 4 varieties commonly planted: “Castilla”, “Brazo”, “Gato” and “Criolla” [34]. *R. glaucus* is the *Rubus* species of major commercial importance and greater acceptance among farmers, industry and consumers in Ecuador; so that, 98% of cultivated blackberries are Andean blackberries, which are consumed fresh or processed into products such as frozen pulp, juice, jam, or wine [33, 35]. Moreover, *R. glaucus* fruits are a promising source of natural colorants (anthocyanins) [36].

R. glaucus has a wide altitudinal adaptation, growing between 1.500 to 3.200 m. However, it achieves optimal development between 2.500 to 3.100 m in moderately cold climates with temperatures around 12 to 18°C, high relative humidity (80–90%), high luminescence and an annual rainfall of 500 to 10000 mm well distributed. The Andean blackberry is susceptible to frosts, so it is important to know the microclimate before implementing the crop. It grows best in sandy loam soils high in organic matter, phosphorous and potassium; and well-drained soils, since plants are highly susceptible to flooding. The plants have a good adaptation to slightly acidic soils with a pH of 5.5 to 7.5, with an optimal of 7. However, they are susceptible to drought, so it is important to have a water source. The yield is also reduced due to the incidence of several diseases and pests, among which the most important are aphids, mites, spider mites, beetles, mildew, powdery mildew, verticillium wilt or grey mold [37]. Ecuador has about 46.100 hectares with high potential for crop sowing, located mainly in the provinces of Pichincha, Tungurahua, Chimborazo, Carchi and Imbabura (Fig. 2A). However, the highest yield registered in the country so far has been about 5 tons/hectare between 2001 and 2006 [34]. The first harvest of *R. glaucus* berries starts between 10 and 12 months after transplantation; then weekly harvests are performed continuously, with some periods of production concentration [38]. The production increases over time and stabilizes at 18 months, finding that the timely production of plants could be 10–15 years, depending on their management [37]. These berries are highly perishable during postharvest handling and about 30% of the harvested product is discarded due to difficulties in postharvest conservation, which results in a short lifespan (approximately 10 days) [31].

2.3. Nutrients

According to its nutrient profile (Table 1) Andean blackberry is low in total calories, with a 100 g serving providing only 43 kcal [39]. Their high fiber content (5.3 g/100 g of fruit) can contribute to control calorie intake by its satiating effect, and coupled with the fructose content (>50% of total sugars) may regulate blood sugar levels by slowing digestion. The fat contained in the oil of blackberry seeds is formed approximately by 82.11% of unsaturated fatty acids, being a source of healthy essential fats. The fat-soluble vitamins as vitamin K and tocopherols have also been identified in the seeds, while most interest has focused on the high levels of the water-soluble vitamin C present in the flesh, which can reach 21 mg/100 g of fresh weight (FW). Besides vitamin C, the folate content in blackberry is another feature that allows to highlight that, among fruits, blackberry is one of the richest natural sources of this essential micronutrient with a content $\sim$25 μg/100 g FW. Moreover, the Andean blackberry, although to a lesser extent, is a source of other vitamins such as thiamin, riboflavin, niacin, vitamin B6 and vitamin A, as well as several minerals such as calcium, magnesium, phosphorus and potassium [39].

2.4. Phytochemistry

Andean blackberry is a natural source of polyphenols mainly represented by the extensive class of phenolic compounds that have been associated with significant beneficial effects on human health [40]. The major class of phenolic compounds is represented by the flavonoids (anthocyanins, flavonols, flavanols), followed by hydrolyzable tannins (gallic and ellagic acid derivatives) and phenolic acids (mainly hydroxycinnamic acids) (Table 2).

Anthocyanins (ACYs) are the phenolic compounds responsible for the red to purple to black pigments of fruits and vegetables [40]. Although there are few studies, some investigations have quantified the total anthocyanin content in Andean blackberry, reporting values of about 45 mg/100 g FW [23]. Approximately 10 different ACYs pigments have been described, with cyanidin-derivatives as the most predominant, while pelargonidin-derivatives are frequently identified, although only in smaller proportions [31, 40–43] (Table 2). Glucose seems to be the most common substituting sugar in Andean blackberry ACYs, although others substituents as rutinose, sambucus, and xylosylrutinoside moieties have been also identified attached at the C3 position of the flavin structure [40].

Because of their important impact on human health, ellagitannins (ETs) represent another important group of phytochemicals to consider in Andean blackberry. ETs consist of different combinations of gallic acid and hexahydroxydiphenic acid with glucose, forming a group of structures such as monomers (ellagic acid [EA] glycosides), oligomers (sanguiin H-6 and Lambertianin C), and complex polymers. Although ETs have often been identified as the active principals in medicinal plants [23, 43], the ETs content and composition in blackberry have been characterized only recently. The total contents of ETs in Andean blackberry have been estimated approximately of 3547 mg of ellagic acid equivalent/kg of fresh weight (FW) [43], with Lambertianin C and Sanguiin H-6 as the most representative (Table 2), and as a basic unit of many ETs. Moreover, ellagic acid as well as gallic and ellagic acid (EA) derivatives have been also identified.

A)

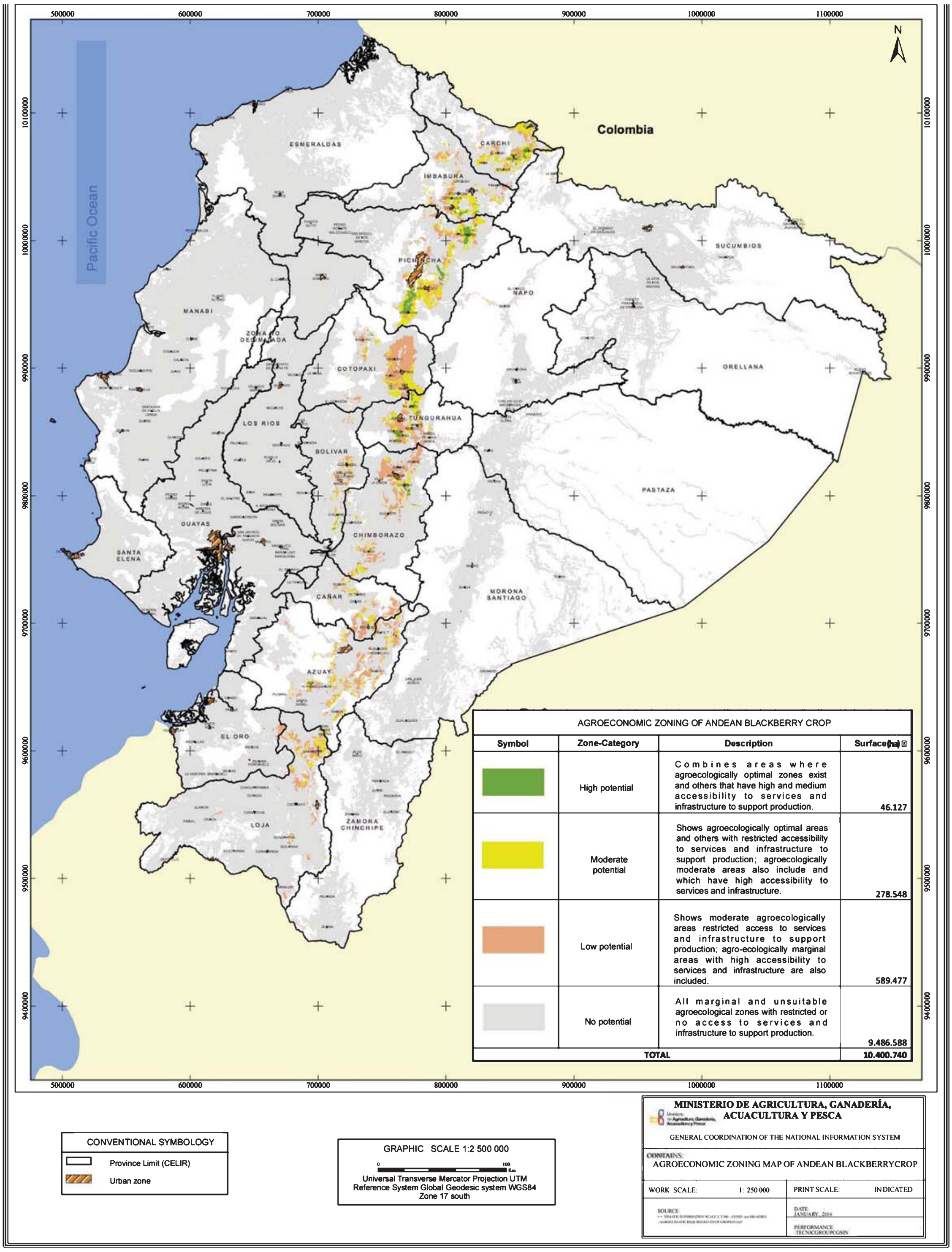

Fig. 2. (*Continued*)

B)

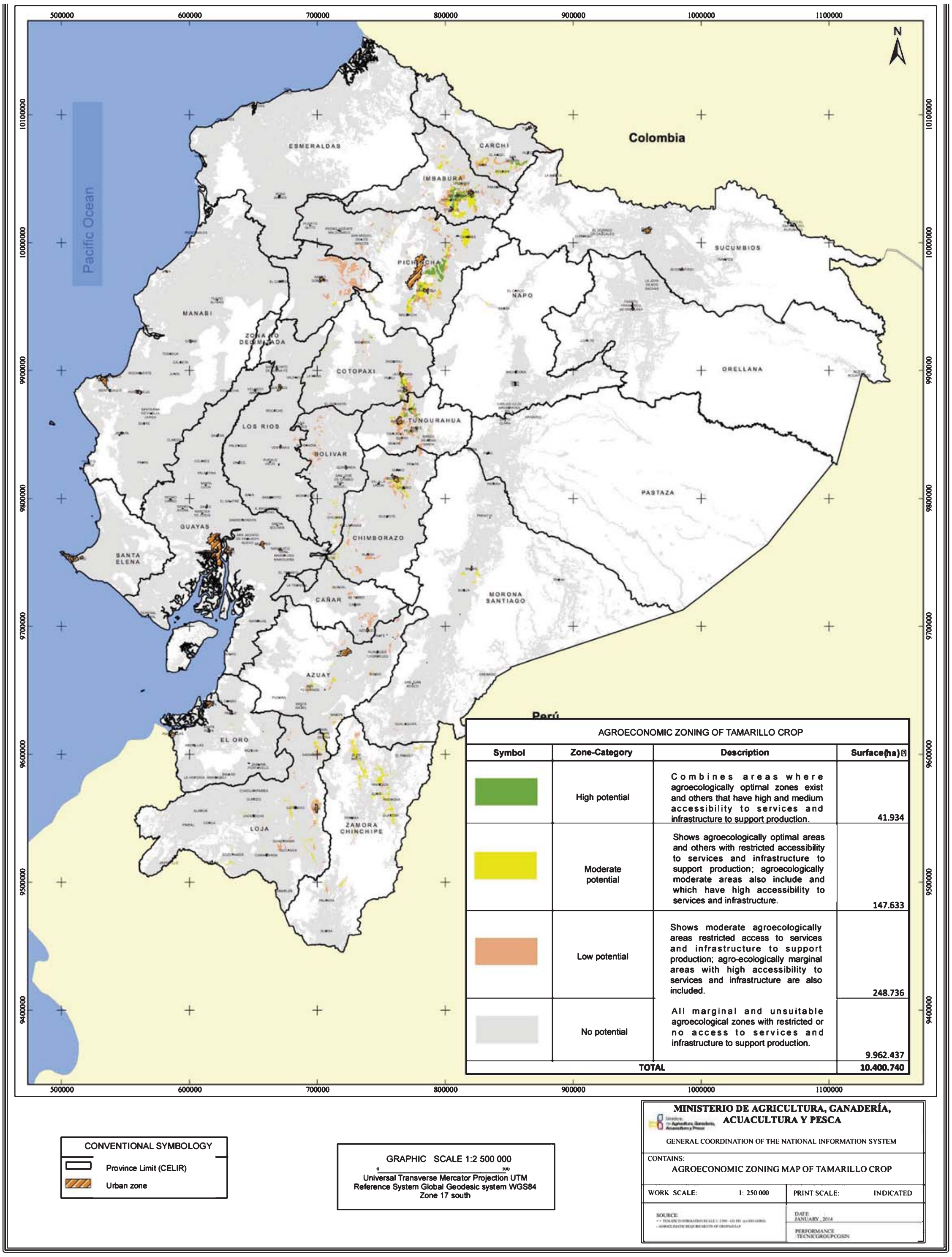

Fig. 2. (*Continued*)

C)

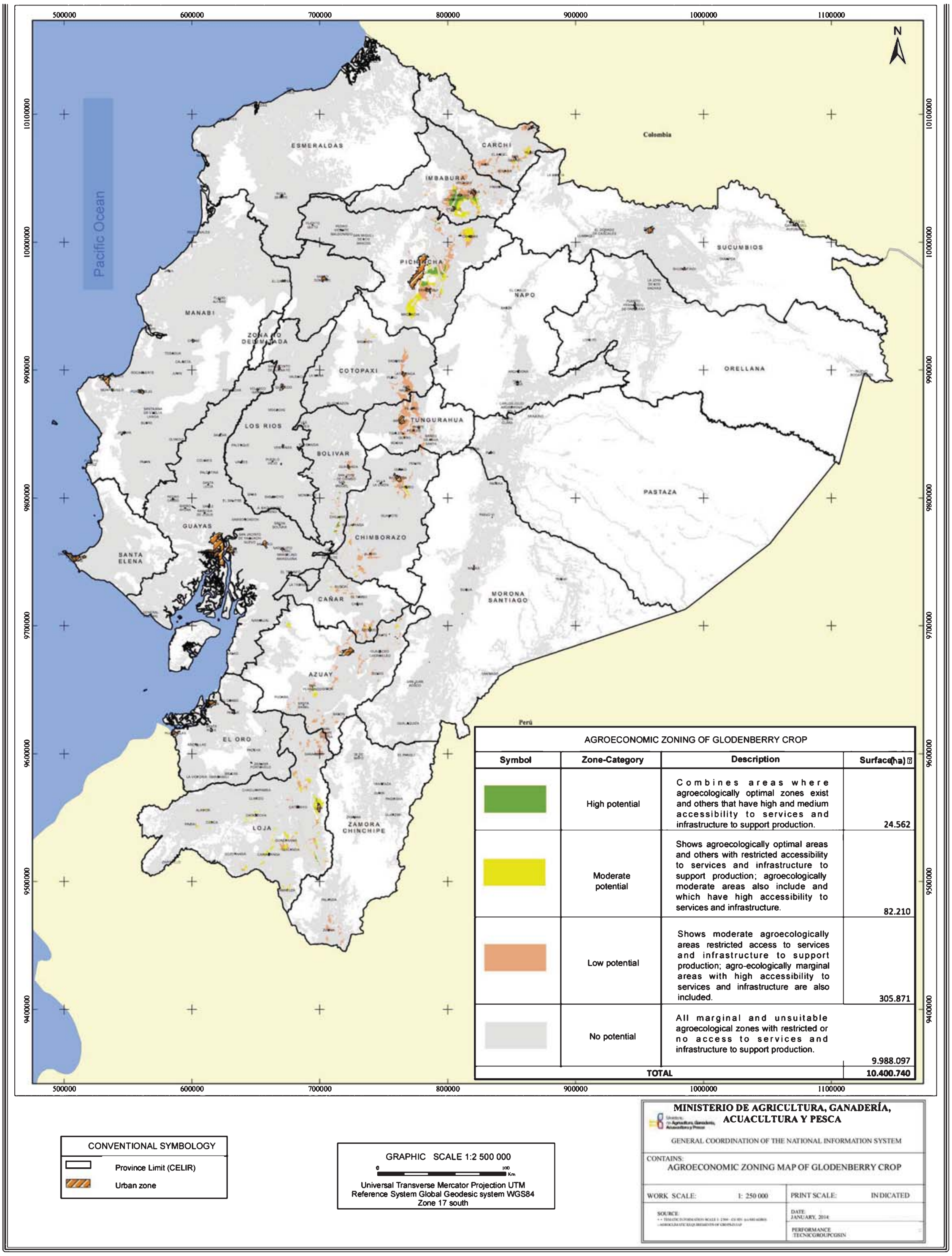

Fig. 2. Agroeconomic zoning maps of Andean blackberry (A), tamarillo (B) and goldenberry (C) crops throughout Ecuador modified from Bucheli et al. (2014) [34, 63, 89].

Table 1
Nutrient composition of fresh Andean blackberry *(R. glaucus* Benth.) [28]

Type	Nutrient	per 100 g
proximates	water (g)	88.15
	energy (kcal)	43
	protein (g)	1.39
	carbohydrates	9.61
	total lipid (g)	0.49
	dietary fiber (g)	5.3
	sugars (g)	4.88
	sucrose (g)	0.07
	glucose (g)	2.31
	fructose (g)	2.40
minerals	calcium (mg)	29
	iron (mg)	0.62
	magnesium (mg)	20
	phosphorus (mg)	22
	potassium (mg)	162
	sodium (mg)	1
	zinc (mg)	0.53
	copper (mg)	0.17
	manganese (mg)	0.65
vitamins	Vitamin C (mg)	21.0
	Thiamin (mg)	0.02
	Riboflavin (mg)	0.02
	Niacin (mg)	0.64
	Vitamin B-6 (mg)	0.03
	Folate (μg)	25.0
	α-tocopherol (mg)	1.17
	β-tocopherol (mg)	0.04
	γ-tocopherol (mg)	1.34
	Δ-tocopherol (mg)	0.90
	vitamin K (μg)	19.8
Lipids	Saturated (g)	0.01
	Monounsaturated (g)	0.04
	Polyunsaturated (g)	0.28

Andean blackberry also contains small amounts of other phenolic compounds. The content and composition of flavonols have been reported [43], being mostly identified as derivatives of quercetin and kaempferol, with quercetin derivatives as the most abundants. Flavanols are the only class of flavonoids that do not occur naturally as glycosides. These compounds have been identified in Andean blackberry in monomeric form such as epicatechin and flavanol derivative. Finally, phenolic acids in Andean blackberry are mainly hydroxycinnamic acids (caffeic, *m*-coumaric, *p*-coumaric, and ferulic acid) [23], which have been identified as minor constituents.

2.5. Biological activities and health effects

R. glaucus fruits play an important role in Andean culture because of their use in health and nutrition. In general, berries have been long studied for their biological activity, having been focused fundamentally on species produced

Table 2
Polyphenolic composition reported in Andean blackberry (*R. glaucus* Benth) [28]

Class	Goup	Compound	Ref.
Phenolic acids	Hydroxycinnamic acids	Caffeic acid	23
		Coumaric acid	23
		Ferulic acid derivatives	23
Flavonoids	Flavanols	Epicatechin	43
		Flavanol derivative	43
	Flavonols	Quercetin-glycosides	43
		Quercetin-3-glucuronide	43
		Quercetin-3-arabinoside	43
		Kaempferol-3-glucuronide	43
	Anthocyanins	Cyanidin-glycoside	43
		Cyanidin-3-glucoside	23
		Cyanidin-3-rutinoside	23
		Cyanidin-3-sambubioside	42, 31
		Cyanidin-3-glucoside	42, 31
		Cyanidin-3-xylosylrutinoside	42, 31
		Cyanidin-3-rutinoside	42, 31
		Pelargonidin-3-glucoside	42, 31
		Pelargonidin-3-rutinoside	42, 31
Hydrolyzable tannins	Ellagitannins	Gallic acid	23
		Gallic acid derivatives	23
		Ellagic acid	43
		Ellagic acid derivatives	43
		2 ellagitannins	43
		Lambertianin C	43
		Sanguiin H-6	43

in the United States and Europe. Thus, despite the effects of Andean berries in human health they have been poorly studied.

The consumption of Andean blackberry in Ecuador is widespread, which is further favored due to its availability almost all year. This allows a large consumption mainly as fresh fruit or juices, and to a lesser extent as processed forms such as jams and jellies. The fact that most fruits are consumed in natural forms without the intervention of industrial processes allows the preservation of their phytochemicals and therefore its nutritional and health properties.

According to the Ecuadorian Andean popular culture, consumption of *R. glaucus* satisfies hunger and helps digestion, makes stronger the body against disease and enhances the senses [44]. These healthy properties could be explained in a simple way if it is considered that Andean blackberry can favor intestinal transit due to the high presence of fibers and phytochemical content such as vitamin C and ACYs that serve as antioxidants. The amount of potassium that contains helps the generation and transmission of nerve impulses, as well as people with strong muscle activities. Although there is no concrete scientific evidence of the health effects of Andean blackberry, several studies in other varieties of blackberries can justify the beneficial effect of consuming this kind of fruit.

An example would be if the ACYs content in the fruit is considered. ACYs are reported to exert an important antioxidant capacity, as well as anti-inflammatory, antiviral, antiproliferative and anti-carcinogenic properties [45]. Moreover, currently there is special interest in the health benefits of the ETs of these fruits. Health benefits of particular blackberry ETs and EA have not been explored so far, although recent studies of ETs and EA detailed the anti-inflammatory, antimicrobial, prebiotic, antioxidant, estrogenic and/or antiestrogenic effect of dietary ETs and EA [40].

2.5.1. Antioxidant capacity (AC)

When referring to the biological properties of berries, the first aspect that is highlighted is its high AC. The AC of blackberry was one of the first aspects to be studied and for a long time was taken as the main justification for its beneficial effects on health. At present, it is known that its health effects are not only linked to these biological properties, which are beyond the antioxidant properties. Despite this, the AC of berries cannot be put aside, whereof the main responsibilities are the vit C and ACYs.

Living organisms present a reduction-oxidation system that is necessary to maintain a balance between free radicals generated and the antioxidant system. The formation of large amounts of free radicals may cause oxidative stress (OS), accelerating the aging and causing many of the principal degenerative diseases that are currently affecting humanity [46]. One of the ways through which the harmful effects of oxidative stress can be prevented and counteracted is the daily consumption of natural antioxidants. The most significant results in the berries intervention studies in healthy humans have been the significant increases in the AC of plasma after an acute [47–49] or a protracted [50] strawberries intake. In terms of AC, one study ranked the AC of blackberries third highest after strawberry and black raspberry on the basis of their ORAC results [51]. These results can be attributed to the high amounts of acylated ACYs in blackberry. ACYs act by scavenging free radicals, with a 3, 4-dihydroxy substituent in the B ring being a key criterion for radical scavenging. They react readily with radicals such as hydroxyl ($^{\cdot}OH$), azide ($N3^{\cdot}$), and peroxyl ($ROO^{\cdot}$) to form stable flavonoid radicals, and thus reducing OS [52]. Moreover, ACYs also act protecting fatty acids from oxidation and enhance fatty acid stability by reacting with α-tocopherol radicals to form α-tocopherol. The antioxidant function of ACYs is also evidenced by its capacity to chelating metal ions at moderate pH levels with their ionized hydroxyl groups of the B ring [52].

2.5.2. Health benefits

At present, cardiovascular diseases (CVD) have been classified as the world's "biggest killers" and are considered one of the major causes of mortality among non-transmittable diseases [53]. Numerous scientific evidences support the hypothesis that consumption of berries can positively affect the risk factors involved in CVD. Therefore, the effects of berries in the prevention of CVD have been demonstrated by their capacity to inhibit inflammation and platelet aggregation; improve endothelial function, plasma lipid profile and free radical scavenging; or increase low-density lipoprotein (LDL) resistance to oxidation [54]. The consumption of Andean blackberry could affect pathways related to cardiovascular health by several different mechanisms. The ability to protect against oxidation could be considered an appropriate mechanism related with the phytochemical composition of Andean blackberry. In fact, Andean blackberry is a rich source of some of the most potent dietary antioxidants *in vitro*, such as vitamin C, ACYs and ETs [31, 40–43].

Elevated levels of LDL in plasma are considered a risk factor for CVD [55]. The high contents of cyanidin glycosides in blackberries have been associated with its AC and its ability to protect against LDL oxidation, whereas the hydroxycinnamic acids are most important in the liposome oxidation system. Phenolic compounds from berries have shown protective effects against CVD by their capacity to inhibit the oxidation of LDL by quenching free radicals through donation of hydrogen molecules [55, 56]. It has also been demonstrated that berries phenolics protect LDL from hydrogen peroxide-induced oxidation in human endothelial cells *in vitro* [57]. *In vitro* studies have demonstrated that ACYs are able to protect human primary endothelial cells by suppressing the secretion of cytokine-induced chemokine monocyte chemotactic protein 1 (MCP-1), a protein directly involved in atherogenesis through its chemotactic function to sites of infection or inflammation [58]. Recently it has also been shown that consumption of berries, specifically strawberries, significantly decreased the number of activated platelets, compared to baseline, which is a critical factor in the pathogenesis of CVD [59]. Moreover, *in vitro* studies have shown that berries flavonoids are able to reduce platelet aggregation and increase platelet nitric oxide production [60].

Besides CVD, cancer is classified as the second cause of death in developed countries. Cancer is a complex process that begins with a cancer cell caused by DNA damage, which continues with accumulation of mutations, promotion of cell proliferation and tumor expansion, and finally progression to malignancy and metastasis [61]. Many studies have demonstrated the potential cancer chemopreventive activities of berries [61]. The phytochemicals present in berries may modulate initiation, promotion, and progression of cancer [62]. The possible anticarcinogenic mechanisms include antioxidant activity, stimulation of antioxidant enzymes; inhibition of carcinogen-induced DNA adducts formation and enhancement of DNA repair [57]. Although antioxidation plays a crucial role in the anticancer capacity of berries, recent studies have exposed the role of berries phytochemicals in modulating cellular processes associated with cancer progression, such as detoxification activity, induction of apoptosis, antiproliferative, and antiangiogenic activity, many of which have been attributed to ACYs. It has been also shown that ACYs are able to induce phase II enzymes, and therefore, inhibiting possible DNA damage caused by carcinogens [57].

The results here exposed, allow the conclusion that Andean blackberry is an important source of natural antioxidants with potential health effects and that specific blackberry components may be involved in different chemical and molecular pathways in exerting their antioxidant and anticarcinogenic effects and in preventing CVD, thus stressing the need for further investigations.

3. Solanum betaceum C

3.1. Botanical aspects

The species is indigenous to the Andean region of Bolivia, Chile, Ecuador, Argentina and Peru, where it has been given different common names such as tamarillo, limatomate, tomate de monte, tomate de árbol, tomate de la paz or tree tomato in English-speaking countries [20]. *S. betaceum* is a small pubescent tree that reaches from 2 to 5 m in height and rarely 7 m. It has a single, short, monopodial and grey trunk branched into 2 or 3 branches. The alternate, simple and entire leaves are usually grouped at the tips of the branches with a robust petiole and the lamina is ovate, subcarnose, shortly acuminate with cordate base and slightly pubescent on the underside. The flowers are fleshy, pink, hermaphrodites, pentamerous, fragrant and pedicellates and gather in groups of 3 to 10 in axillary cymes or racemes near the ends of the branches. The fruits are ellipsoidal or ovoid, obtuse or acute at apex, with lengths from 4 to 10 cm and wide of 3 to 5 cm, glabrous, yellow to orange, red, or purple, often with darker longitudinal marks. The color of the fruit once ripe depends on the variety. Inside the fruits, the mesocarp is orange, fleshy and contains numerous small, round, flat and hard seeds (Fig. 1B) [20].

3.2. Agronomic aspects

In addition to the aforementioned countries, Andean blackberry is cultivated in Argentina, Australia, Brazil, Colombia, Indonesia, Kenya, Malaysia, Papua New Guinea, Philippines, Thailand, United States, Venezuela, Vietnam and New Zealand [20]; and it is used to be consumed fresh, seasoned, in salads, juices, smoothies, sorbets, alcoholic drinks, puree, sauces, cooked dishes, desserts or jams. In Ecuador, 54% of total provinces (Azuay, Bolívar, Carchi, Chimborazo, Cotopaxi, Imbabura, Morona Santiago, Napo, Loja, Pichincha, Sucumbíos, Tungurahua and Zamora Chinchipe) are producers and in 2013 the area planted was almost 6.000 hectares (Fig. 2B) [63]. The country currently produces three different varieties: the “common tamarillo” (elongated, purple and orange), the “round tamarillo” (reddish orange) and the “blackberry tamarillo” (oblong and purple). However, the expansion of this crop is limited by factors such as the lack of clear differentiation among varieties, low fruit quality (heterogeneity and phytosanitary problems), the use of inappropriate varieties or replacement of local varieties by materials from other origins not adapted [64]. Some works studying genetic diversity have indicated the existence of considerable variability and that it is possible to select materials with characteristics more suitable for fruit market [19, 64–66]; however, more investigations related to its conservation and genetic improvement are needed [64, 67].

The tamarillo is a subtropical tree able to bloom from altitudes of 1.000 to 3.000 m in the tropics and subtropics; however, in the coldest areas of the subtropics it may develop from 300 to 1.000 m. Despite being tolerant to low temperatures above 10°C, –2°C temperatures can cause important damages to young foliage, juvenile branches and seedlings. The optimum temperature for its growth of is around 18 to 22°C and requires annual precipitation of 600 to 800 mm. Cool temperatures promote flowering, while high temperatures affect both bloom and fruiting, as prolonged droughts do. The tree is susceptible to strong winds as it has fragile branches, weak foliage and superficial roots, which also prevents sowing in heavy clays and compacted or waterlogged soils. Therefore, plants grow best in well-drained, friable and light soils [20]. The yield is also reduced due to the incidence of diseases such as anthracnose, powdery mildew, some viruses and nematodes [68]. Thus, the average yield in Ecuador during 2012 was about 7 tons/hectare. Nevertheless, the country has about 41.900 hectares with high potential

Table 3
Nutrient composition of fresh tree tomato *(Solanum betaceum* C.) [20]

Type	Nutrient	per 100 g
proximates	water (g)	87.8
	energy (kcal)	31
	protein (g)	1.5
	carbohydrates	10.3
	total lipid (g)	1.28
	dietary fiber (g)	4.2
	sugars (g)	4.7
	sucrose (g)	2.5
	glucose (g)	1.0
	fructose (g)	1.2
minerals	calcium (mg)	11.3
	iron (mg)	0.94
	magnesium (mg)	22.3
	phosphorus (mg)	13.1
	potassium (mg)	349
	sodium (mg)	8.9
	zinc (mg)	0.20
	copper (mg)	0.20
	manganese (mg)	0.20
vitamins	vitamin C (mg)	33.9
	vitamin A (I.U)	2475
	carotene (mg)	0.65
	thiamine (mg)	0.13
	riboflavin (mg)	0.048
	niacin (mg)	1.0

for sowing crops, located mainly in the provinces of Tungurahua, Carchi, Chimborazo, Cotopaxi, Imbabura and Pichincha (Fig. 2B).

3.3. Nutrients

The consumption of products low in sodium, rich in dietary fiber, potassium and other minerals, vitamins and antioxidant phytochemicals, are characteristic of well-balanced diets. According to their nutritional profile (Table 3), tree tomato fruits are low in total calories (31 kcal/100 g) and sodium (8.9 mg/100 g), but rich in dietary fiber (4.2 g/100 g), potassium (349 mg/100 g), as well as vitamins such as the water-soluble vitamin C (33.9 mg/100 g) [20]. To these characteristics a group of ACYs and carotenoids with high antioxidant properties is added to be discussed below, that make the tree tomato an excellent choice as a source of dietary natural compounds beneficial to health.

3.4. Phytochemistry

The studies concerning the chemical composition of tree tomato are relatively recent [36]. At present, the tree tomato is a promising product for export, and due to its color, the red variety has been the most accepted internationally. The tree tomato fruits predominantly contain anthocyanins and carotenoids, while phenolic acid and other flavonoids have been identified as minor constituents [36]. Thus, it has been reported that the levels of anthocyanins and carotenoids

Table 4
Phytochemical composition reported in tree tomato *(Solanum betaceum* C.) [22, 36, 69]

Class	Goup	Compound
Phenolic acids	Hydroxycinnamic acids	Dicaffeoylquinic acid
		Caffeoylquinic acid
		Caffeoyl glucose
		Feruloyl glucose
Flavonoids	Anthocyanins	Delphinidin glucosyl- rutinoside
		Delphinidin rutinoside
		Cyanidin rutinoside
		Pelargonidin rutinoside
		Delphinidin 3-*O*-(6"-*O*-α-rhamnopyranosyl-β-glucopyranosyl)-3'-*O*-β-glucopyranoside
		Delphinidin 3-*O*-(6"-*O*-α-rhamnopyranosyl)-β-glucopyranoside
		Cyanidin 3-*O*-(6"-*O*-α-rhamnopyranosyl)-β-glucopyranoside
		Pelargonidin 3-*O*-(6"-*O*-arhamnopyranosyl)- β-glucopyranoside
Carotenoids	Carotenes	β -carotene
	Xanthophylls	Zeaxanthin
		β-cryptoxanthin
		Lutein

found in tree tomato fruits are approximately of 0.371–0.653 mg/100 g, respectively [20]. About 8 different ACYs pigments have been described, with delphinidin and cyanidin derivatives as the most predominant forms and glucose and rhamnose, in pyranose form, as the most common substituents, while pelargonidin-derivatives have been identified but only in smaller proportions [36] (Table 4).

Besides the ACYs, carotenoids are another important group of compounds identified in tree tomato. Carotenoids are organic pigments that are found in the chloroplasts and chromoplasts of plants, characterized by abundant conjugated double bonds, which are responsible for the potent antioxidant properties of these compounds. The most abundant carotenoids identified in tree tomato belong to the xanthophylls, with zeaxanthin, β-cryptoxanthin and lutein as the most predominant, while β-Carotene, from the carotenes group, have been also reported [22]. For phenolic acids, hydroxycinnamic acids are the majors. Among them, dicaffeoylquinic acid, caffeoylquinic acid, caffeoyl glucose and feruloyl glucose [69] are the most predominant.

3.5. Biological activities and health effects

3.5.1. Antioxidant capacity (AC)

At present, the increasing interest in tree tomato as a potential new crop has led to several studies, mostly related to its chemical composition, while studies related to their biological properties are still scarce. Consumption of fresh fruit or as juice is widespread throughout Ecuador and Andean region. Using the traditional method of preparation of fruit juices in the Andean region, the researchers found that the best antioxidant activity derived from maceration, compared with jams and jellies [18], probably as a consequence of the conservation of some natural antioxidants that, in some cases, may be lost or may decrease their properties through industrial processes. Furthermore, the insoluble matters (pomace) obtained after preparing juice showed a higher antioxidant capacity compared to when it is obtained after the industrialization process [18].

Lipophilic compounds in tree tomato have also attracted interest from researchers. Within these, carotenoids are a group of great interest, especially for his significant AC [69]. The chemopreventive role of carotenoids as antioxidants, anticarcer and antimutagenic has been supported by many epidemiologic studies [70]. The ethyl acetate fraction from tree tomato has exhibited the highest DPPH scavenging activity and Trolox equivalent antioxidant capacity (TEAC) compared with aqueous and ethanolic fractions [69].

Finally, a recent study has shown that one protein with molecular mass around 17 kDa, purified from tree tomato, was able to inhibit uric acid formation and reduce oxidative damage by scavenging hydroxyl radicals and superoxide anion in a dose-dependent manner. This study showed that this protein might constitute a promising source for the production of bioactive peptides, as well as its potential use for the development of functional foods with a beneficial impact on human health [71].

3.5.2. Health benefits

The medical uses of tree tomato are mainly based in empirical knowledge of popular culture. The medicinal uses of tree tomato in Colombia and Ecuador are related to sore throats and flu. The fruit or leaves, previously heated, are applied topically against inflammation of tonsils. For influenza, fruits should be eaten fresh. In Venezuela is used to raise hemoglobin in the treatment of anemia.

Yellow varieties are a good source of carotenes, and xanthins, compounds that possess antioxidant properties and, together with vitamin A, are essential for visual health. Further, vitamin A is also required for maintaining healthy mucus membranes and skin. The fruits are also a very good source of electrolyte, such as potassium, that is an important component of cell and body fluids helping to control heart rate and blood pressure, counteracting the negative action of sodium. Tree tomato in Andean culture has been traditionally used to reduce blood cholesterol levels and to treat respiratory problems. The pulp is also used for the prevention of neurodegenerative diseases and arteriosclerosis, and it has antimicrobial activity. Beyond this, at present the scientific reports about the effect of tree tomato fruit in human health are very limited. The authors found no specific scientific studies about this topic.

4. Physalis peruviana L

4.1. Botanical aspects

P. peruviana is commonly known as uchuva in Colombia, uvilla in Ecuador, aguaymanto in Perú, topotopo in Venezuela or goldenberry and cape gooseberry in English-speaking countries [16]. It is an exotic fruit that belongs to the family *Solanaceae* and genus *Physalis*, with a characteristic tomato-like flavour and appearance (Fig. 1C), but with a taste (sweet and sour) much richer than this [15]. This fruit is native to the Andes, having transcended the history of periods pre-Incan and Incan [16, 72]. Different chromosome numbers may exist among distinct genotypes, thus, it has been reported $2n = 24$ for wild ecotypes, $2n = 32$ for the ecotype grown in Colombia or $2n = 48$ for the ecotype cultivated in Kenya [73, 74]. It has remained intact and without apparent changes in the structure of their germplasm, having been described more than 80 wild species and many cultivars of different regions and countries. These varieties differ from one another in size, color and fruit taste, flower shape, plant height and size [16, 75]. In Ecuador, the most produced varieties are “Kenian” and “Lojan”, both with orange-yellow berries [76]. Although the collections held in genebanks have been partially evaluated for morphological and agronomic traits [74, 77–79], genetic diversity at the molecular level has been little studied [74, 80].

The plants are perennials in subtropical regions and are herbaceous, upright semi-shrubs that can grow to 0.6 to 0.9 m and, in some cases, may grow up to 1.8 m. The flowers are yellow with purple blotches and bell-shaped, and can be easily pollinated by insects, wind and through auto-pollination. The fruits generally weigh between 4 to 5 g and have a diameter from 1.25 to 2.50 cm. They are covered throughout their development and ripening by an accrescent calyx that hangs downwards like a lantern, protecting them against insects, birds, diseases and adverse climatic conditions. Furthermore, this structure represents a major source of carbohydrates during the first 20 days of growth and fruit development. The berries have a brilliant yellow peel and ovoid shape and, contain about 100 to 200 small seeds (Fig. 1C) [16, 81–85].

4.2. Agronomic aspects

Cape gooseberries are commercially produced in Australia, Colombia, China, Ecuador, Egypt, Great Britain, Hawaii, India, Kenya, Malaysia, New Zealand, South Africa, Zimbabwe [16, 81, 82, 86, 87]. The crop was introduced to South Africa by the Spaniards and from there it spread to different countries of the tropic and sub-tropics [16].

Currently, the major producers are Colombia and South Africa, however, is a minor crop [16, 75, 81, 88]. In Ecuador, *P. peruviana* is produced in the provinces of Azuay, Carchi, Cotopaxi, Imbabura and Pichincha, counting over 200 hectares in 2011 [89]. Despite its potential, in most countries *P. peruviana* is a backyard plant, nevertheless in some international markets such as Europe, the fruits have recently reached very high prices [90]. They are usually consumed as fresh fruit, however, they can also be served in salads, cooked dishes, desserts, jams, natural snacks, and canned fruit [75, 81].

It is a crop with high potential able to grow in a wide range of altitudes (sea level to 3300 m) and tolerate low temperatures, growing at an optimum temperature of 18°C. Thus, their growth and development are affected by very high and very low temperatures, suffering irreparable damage below 0°C. The plants require high luminescence and wind protection and it is important to provide enough water during the early growth. *P. peruviana* grows in poor soils, but well-drained and has low fertilization requirements. The plants thrive best in slightly acidic soils, although tolerate pH values between 5.5 to 7.3 with a good organic content and a rainfall between 1000 to 2000 mm. They do not tolerate clay soils because they have superficial roots [15, 16, 82]. *P. peruviana* yield may be hampered by several fungal and bacterial diseases, viruses, beetles, caterpillars, whiteflies or nematodes that cause different symptoms as damping-off, necrosis or wilt [91]. The crop requires approximately 9 months for the first harvest, having a production time ranging from 9 to 11 months after the first harvest, since thereafter productivity and fruit quality are reduced [16]. A single plant can yield up to 300 fruits and 20 to 33 tons/hectare, however in Ecuador due to different factors it is often reduced about 5 to 7 tons/hectare. The country has about 24.500 hectares with high potentiality for crop planting in the provinces of Imbabura, Pichincha, Bolívar, Loja and Tungurahua (Fig. 2C) [89]. The shelf life of the fruits with calyx is 1 month, whereas without calyx is 4 to 5 days [16]. Fruits are long-lasting when stored in a sealed container and kept in a dry atmosphere for several months and they also freeze well [81].

4.3. Nutrients

Cape gooseberry fruit is highly valued for its flavor, texture, color, and nutrients. The fruits are a good source of provitamin A, minerals, fatty acids, vitamin C and vitamin B-complex, such as thiamine, niacin and vitamin B12 (Table 5). The fruits contain approximately 15% of soluble solid, with fructose as the main sugar, which coupled with the high values of fiber regulate blood glucose levels and control calorie intake. The fatty acid profile of *Physalis* has presented a high concentration of fatty acids with beneficial health effects, such as linoleic acid (72.42%). It is noteworthy that linoleic acid-rich diets have been associated as a factor to prevent cardiovascular diseases, atherosclerosis and hypertension. Moreover, saturated fatty acids have represented 12.87% of total fatty acids, with the palmitic acid as the main acid, while stearic acid content represented about of 2.57% [82].

4.4. Phytochemistry

The main bioactive phytochemicals identified in cape gooseberry have been fundamentally withanolides, with withanolides and physalins as the most frequently groups identified. Carotenoids are another of major compounds identified in cape gooseberry fruits, while flavonoids have also been identified, but as minor constituents (Table 6) [82]. Withanolides are a group of steroidal lactones which have been isolated from the genera *Acnistus*, *Datura*, *Jaborosa*, *Lycium*, *Physalis* and *Withania* of the family *Solanaceae* [82, 92], which consist of a steroid backbone bound to a lactone or one of its derivatives produced via oxidation of steroids. This class of steroidal lactones involves an ergostane-type framework which C-22 and C-26 are appropriately oxidized to form a (delta)-lactone ring. Withanolides group is subdivided into nine groups: withanolides, withaphysalins, physalins, nicandrenones, jaborols, ixocarpalactones, perulactones, acnistins and miscellaneous withasteroids. In Cape gooseberry approximately 20 types of withasteroids have been identified (Table 6) [92].

4.5. Health benefits

In folk medicine cape gooseberry is used for treating diseases such as malaria, asthma, hepatitis, dermatitis, diuretic and rheumatism [82]. Other medicinal properties have been attributed to cape gooseberry, including antiasthmatic,

Table 5
Nutrient composition of cape gooseberry *(Physalis peruviana* L.) [82]

Type	Nutrient	Values
Proximates	water (g/100 g)	85.4
	energy (kcal/100 g)	53
	protein (g/100 g)	1.9
	Carbohydrates (g/100 g)	11.2
	total lipid (g/100 g)	0.70
	dietary fiber (g/100 g)	4.9
Minerals	calcium (mg/100 g)	9.0
	iron (mg/100 g)	1.0
	magnesium (mg/100 g)	22.3
	phosphorus (mg/100 g)	40.0
Vitamins	vitamin C (mg/100 g)	11.0
	vitamin A (I.U)	720
	thiamine (mg/100 g)	0.11
	riboflavin (mg/100 g)	0.040
	niacin (mg/100 g)	1.0
fatty acids	palmitic acid (% w/w)	9.38
	palmitoleic acid (% w/w)	0.71
	stearic acid (% w/w)	2.67
	oleic acid (% w/w)	10.03
	linoleic acid (% w/w)	72.42
	α-linoleic acid (% w/w)	0.32
	arachidic acid (% w/w)	1.36
	behenic acid (% w/w)	0.26
	lignoceric acid (% w/w)	0.24
	Saturated (% w/w)	12.87
	Monounsaturated (% w/w)	10.71
	Polyunsaturated (% w/w)	73.78

antiseptic, and strengthener for the optic nerve, treatment of throat affections and elimination of intestinal parasites, amoebas as well as albumin from kidneys. It has an anti-ulcer activity and it is effective in reducing cholesterol level. Moreover, *P. peruviana* is a medicinal plant widely used in folk medicine as an anticancer, antimycobacterial, antipyretic, and immunomodulatory and also used in the treatment of diseases such as malaria, asthma, hepatitis, dermatitis, and rheumatism [82].

P. peruviana has been reported as a natural source of important bioactive compounds such as withanolides and phenolics, which have been associated with a strong oxidant property and prevent peroxidative damage to liver microsomes and hepatocytes [92]. It has been demonstrated that different leaves extracts from *P. peruviana* showed antihepatotoxic activities against CCl4-induced hepatotoxicity [93].

Moreover, it has also been reported that the ethanolic extract of *P. peruviana* (EEPP) was able to inhibit growth and induces apoptotic death of human Hep G2 cells in culture, proving the potent anti-hepatoma activity and the effect on apoptosis of EEPP. A detailed study to define the molecular mechanism of EEPP-induced apoptosis in Hep G2 cells was recently published [94, 95]. These results could be important as an indication of the potentially nutraceutical and economical utility of cape gooseberry as a new source of bioactive phytochemicals and functional foods.

Table 6
Phytochemical composition reported in Cape gooseberry *(Physalis peruviana* L.) [82]

Class	Goup	Compound
Withanolides	Withanolides	withanolide E
		4β-hydroxywithanolide E
		28-hydroxywithanolide E
		(20R,22R)- 5α,6β,14α,20, 27-pentahydroxy-1-oxowith-24-enolide
		(20S,22R)-5β,6β-epoxy-4β,14β, 15α- hihydroxy-1-oxowith-2,24-dienolide
		phyperunolide A
		phyperunolide B
		phyperunolide C
		phyperunolide D
		phyperunolide E
		Phyperunolide F
		withanolid S
		withanolid C
		withaperuvin
		physalolactone
		withaphysanolid
		physalactona
		withaperuvin D
		loliolid
	Physalins	Physalins A,
		Physalins B
		Physalins D
		Physalins F
Flavonoids	Flavonol	kaempferol 3-*O*-rutinoside
		quercetin 3,4',7-trimethyl ether
Carotenoids	Carotenes	α-tocopherol
		β-tocopherol
		γ-tocopherol
		δ-tocopherol

5. Conclusions

The phytochemistry and health benefit uses of two important berries and an aggregate fruit commonly known as a berry, all native to the Andean region, have been reviewed. These plants possess a rich and diversified composition of bioactive compounds as well as health-promoting properties. Nevertheless, studies *in vivo* and *in vitro* related to their biological activities are still limited. Although future research is needed to understand their potential in regard to their use as supplements or as functional foods, the studies reviewed demonstrate the health potential of berries from Ecuador; thus, greater attention should be given to native fruits from this region.

Ecuador is being revalued in recent years due to a number of causes such as its great biodiversity and the improved stability (political, economic and social). This together with the increasing demand of natural medicinal products and new bioactive compounds in the last decades is opening a new range of opportunities including new sources of funding for investigations and new research lines. Governmental institutions as the National Institute of Agricultural Research (INIAP), universities and private businesses are boosting the research and trying to highlight the richness and potentialities of the country. So, an increasing number of researches and programmes are approaching the conservation, restoration and dissemination of ancestral knowledge, many of them addressing traditional medicine (plants and uses), the search of new bioactive compounds or new applications. Therefore, great potentialities are making their way and awakening new desires and endeavours, leading to enrich society with new bioactive principles, properties and applications and also allow the conservation of traditional practices and Ecuadorian plant species.

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