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Native plants from the genus *Vaccinium* in Colombia and their potential uses. A review

Plantas nativas del género *Vaccinium* en Colombia y sus usos potenciales. Una revisión

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Plants of *Vaccinium floribundum* (department of Cundinamarca, 3,100 m a.s.l.).

Photo: S. Magnitskiy

ABSTRACT

The Andean Region of Colombia has a large variety of species with diverse ethnobotanical uses, including industrial, medicinal and food uses. Among these plants are several wild species from the genus *Vaccinium*, which are native to the mountainous regions of the country. This review deals with potential uses for agraz (*V. meridionale*) and agracejo (*V. floribundum*) in Colombia, focusing on the nutritional potential of these plants and their importance for food security in terms of products made from their fruits and leaves. In addition, this review looks at possible negative effects from anthropic activities and climate change on wild plants from the genus *Vaccinium*.

Additional keywords: native fruit crops; biodiversity; promissory crops; Ericaceae.

RESUMEN

La región Andina de Colombia tiene una gran variedad de especies con diferentes usos etnobotánicos, incluyendo usos industriales, medicinales y alimenticios. Entre estas plantas se encuentran varias especies silvestres del género *Vaccinium*, que son nativas de las regiones montañosas del país. Esta revisión trata sobre los usos potenciales de agraz (*V. meridionale*) y agracejo (*V. floribundum*) en Colombia, centrándose en el potencial nutricional de estas plantas y su importancia para la seguridad alimentaria en términos de productos elaborados a partir de sus frutos y hojas. Además, esta revisión analiza los posibles efectos negativos de las actividades antrópicas y el cambio climático en las plantas silvestres del género *Vaccinium*.

Palabras clave adicionales: frutales nativos; biodiversidad; cultivos promisorios; Ericaceae.

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INTRODUCTION

The Andean region of Colombia possesses a large variety of wild species that can be used industrially, medically, and for food. Among these species, plants from the Ericaceae family are widely distributed in the mountains of this country, including páramos and mountain Andean forests. Worldwide, the Ericaceae family includes about 124 genera and more than 4,100 species, most of which are shrubs and small trees, including fruit crops (Stevens *et al*., 2004).

The Andean region is one of the centers of biodiversity for Ericaceae, with most distributed in Colombia and Ecuador (Luteyn, 2002). The neotropics have 46 genera for Ericaceae, with more than 800 species; more than 90% of these species are endemic to the neotropics (Luteyn, 2002). In Colombia, 24 genera and 278 species have been reported for Ericaceae, with the greatest diversity described for the *Cordillera Occidental* and Chocó regions (Pedraza-Peñalosa *et al*., 2015).

The mountain forests, as well as the páramo and subpáramo, are natural reserves for wild Ericaceae in the country. The distribution of Ericaceae in the mountain regions is conditioned by various ecological limitations to which these plants are adapted. In particular, páramo conditions impose a high environmental pressure on plants with low air temperatures, very high relative air humidity, high incidence of UV light, strong winds, and poor soils (Cruz and Lasso, 2021; Becerra *et al*., 2022). Altitude and associated environmental factors are important indicators that determine the distribution of wild populations of Ericaceae in Colombia (Ligarreto, 2009).

These plants are typical species in the vegetation of humid and cold mountainous ecosystems, such as cloud forests and shrublands, located between 2,000 and 3,500 m a.s.l. In these areas, Ericaceae plants serve as a food source for insects, birds, and mammals. Also, they provide economic income for the inhabitants of the region through the sale of fruits. The most representative genera of Ericaceae fruit species in the neotropics are *Cavendishia* (130 species), *Psammisia* (70 species), *Thibaudia* (60 species), *Vaccinium* (40 species), *Macleania* (40 species), *Disterigma* (40 species), and *Gaultheria* (37 species) (Smith, 2004).

The present review deals with the prospects for the ethnobotanical use of native plants from the genus *Vaccinium* in Colombia. For this, the indexed databases of Scopus and Scielo were reviewed using bibliographic references for the last 20 years. This review addressed the nutritional potential of these plants and their importance for human health in relation to products prepared from the fruits and leaves. The possible negative effects of anthropic activity on wild populations of plants from the genus *Vaccinium* in Colombia were considered.

NATIVE *VACCINIUM* PLANTS OF COLOMBIA

Worldwide, the *Vaccinium* genus includes about 425 species, with blueberries having a high commercial importance (Stevens *et al*., 2004; Martău *et al*., 2023). The native plants of the *Vaccinium* genus of Colombia are the closest relatives to commercial blueberries, which have multiple uses, such as in the food industry (Edger *et al*., 2022). Wild *Vaccinium* species are considered "native blueberries" of Colombia. Studies on their diversity, distribution, and possible use have increased in recent years since *Vaccinium* spp. is one of the fruit species with the highest content of flavonoid-type antioxidants, which benefit human health (Martău *et al*., 2023).

Several native species of the *Vaccinium* genus are found in Colombia, with *V. meridionale* (common names: agraz, mortiño) and *V. floribundum* (common name: agracejo) as the most studied species. Additionally, there are reports of *V. euryanthum, V. corymbodendron, V. singularis* (Salinas and Betancur, 2007), and, according to Luteyn and Pedraza-Peñalosa (2012), other *Vaccinium* species.

V. euryanthum is a shrub belonging to the table-mountain vegetation of the Serranía de Chiribiquete (~ 800 m a.s.l., well below the "typical" altitudinal limit for native *Vaccinium* species) in the Amazon region (Cárdenas *et al*., 2017). The presence of *V. euryanthum* in this area is due to ancient geological events, such as the origin of the Chiribiquete mountains from the Guiana Shield (Cortés *et al*., 1998); this species was

reported by Luteyn (1989) in the rocky formations of the Guiana Shield in Venezuela.

V. corymbodendron is a tetraploid species from the high-altitude regions of Colombia, which can flower at temperatures below freezing (Ehlenfeldt *et al*., 2018), with most reports obtained from the Antioquia department (Sierra *et al*., 2005; Bernal *et al*., 2019). At the same time, the presence of *V. corymbodendron* may be questionable. In field surveys (2010-2022) in the departments of Cundinamarca and Boyaca, such plant was unfamiliar to local people, and it could be that the plants of *V. meridionale* or *V. floribundum* have been mistakenly identified as a separate species of *V. corymbodendron*. Almost no published reports exist for the new species *V. singularis,* described for the first time by Salinas and Betancur (2007) in the Chocó Biogeographic Region (department of Nariño, 1,200-1,800 m a.s.l.). Therefore, the present review is focused on practical uses for two native species: *V. meridionale* and *V. floribundum*; the commercially cultivated blueberries ("highbush" blueberry *V. corymbosum* and other related species/hybrids) were not considered.

Vaccinium blueberries are known as a "superfood" because of the high content of antioxidants in fruits, and their consumption is geared towards human health. Both fruits and leaves of *V. meridionale* and *V. floribundum* possess antimicrobic, antifungal and anticancer properties (Lopera *et al*., 2013; Maldonado-Celis *et al*., 2014; Sequeda-Castañeda *et al*., 2016; González *et al*., 2017; Llivisaca *et al*., 2018; Shen *et al*., 2018). Based on these properties, most of the existing bibliographic references deal with potential uses for food and medicine.

AGRAZ, *VACCINIUM MERIDIONALE* SWARTZ

This plant is a tetraploid evergreen species native to the Andean forests (Ecuador, Colombia, Venezuela, Perú) and mountains of Jamaica, and grows at altitudes of 2,000-3,200 m a.s.l. in Colombia (Fig. 1) (Fischer *et al*., 2022). The largest number of reports on wild populations comes from the departments of Cundinamarca, Antioquia, Boyaca, and Magdalena (Sierra Nevada de Santa Marta) (Ligarreto, 2009). *V. meridionale* has a tree or shrub-type morphology, with a height that varies from 0.2 to 5.0 m, while exceptional tree individuals (Macheta, Cundinamarca department, 2,090 m a.s.l.) exceed 15 m in height (S. Magnitskiy, unpubl. data). The leaves are small, ovate or elliptic (Ligarreto, 2009), becoming cold-hardy at higher elevations; the leaf water content could be as low as 50% depending on the ecotype and leaf age. The fruit is a berry with an 8-15 mm diameter that is blue, dark purple or black when ripe. Ripe fruits commonly possess a waxy layer; this characteristic is also typical for deciduous *Vaccinium* species native to Northern Europe and Western United States (Trivedi *et al*., 2021).

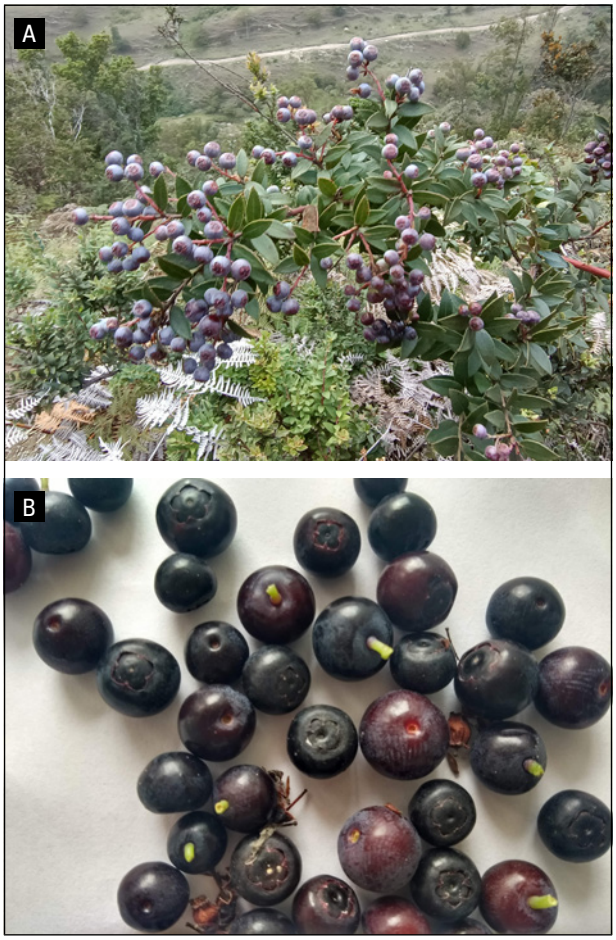

Figure 1. (A) *Vaccinium meridionale* plant in a wild population in the department of Santander (3,000 m a.s.l.) and (B) mature fruits.

Plant height and overall plant morphology are highly variable characteristics in wild populations of *V. meridionale* (Ligarreto *et al*., 2009). These plants can have a small height (~ 0.5 m) and almost runner-type morphology, such as in several populations in San Miguel de Sema (2,650 m a.s.l., Boyaca department) grown under canopy of oak-pine forests. With a tree-like

appearance, *V. meridionale* plants are notable for the high number of flowers per inflorescence (Ehlenfeldt and Luteyn, 2021). A tree-like morphology, together with a large height, can be attractive for cultivation of these plants in the open field as a commercial crop.

Ripe fruits from Colombia have high contents of antioxidants, including an average anthocyanin content of 329.0 mg cyanidin 3-glucoside equivalent/100 g fresh weight (FW), total phenolic content of 758.6 gallic acid equivalent/100 g FW, and ABTS radical scavenging activity of 45.5 μmol Trolox equivalent/g FW, where cyanidin 3-galactoside was the main anthocyanin, and chlorogenic acid was the most abundant non-anthocyanin phenolic compound (Garzón *et al*., 2010).

In Colombia, *V. meridionale* fruits are sold at local markets or sold to intermediaries, mainly in the departments of Boyaca, Cundinamarca, and Antioquia. These are consumed fresh or in desserts, yogurt, jams, juices, or wine. For more than a decade, this plant has been recognized as a promising crop in Colombia (Ligarreto, 2009).

According to various authors, the fruits and leaves of this plant have several possible uses in food and beverages. The vinegar prepared from *V. meridionale* berries had considerable antioxidant activity because of the high content of bioactive compounds (Ochoa, 2014), which are beneficial for human health. Adding *V. meridionale* fruit extracts increased the antioxidant contents of beverages (Zárate *et al*., 2023).

The leaves of *V. meridionale* contain mono and polyphenolic compounds and can be used for tea drinks (Zapata-Vahos *et al*., 2015; Borda-Yepes *et al*., 2019). As compared to deciduous *Vaccinium* species, such as *V. myrtillus*, the fresh leaves of *V. meridionale* have notably less flavor when steeped in hot water but apparently this changes when processing leaves for tea. The leaves of *V. meridionale* have high levels of antioxidants (Zapata-Vahos *et al*., 2015), and their catechin concentrations are comparable with catechin concentrations in black tea leaves (Borda-Yepes *et al*., 2019). *V. meridionale* can accumulate higher contents of anthocyanins in leaves when plants are grown under stressful conditions, including low air temperatures or increased incidence of UV-radiation, which are seen at higher altitudes (Becerra *et al*., 2022). The accumulation of phenolic compounds under stressful conditions was also reported for *Vaccinium* species in temperate regions (Karppinen *et al*., 2016). An easy method for increasing the contents of anthocyanins in *V. meridionale* leaves during cultivation consists of mineral nutrition with nitrogen applied to the plants as nitrate (González *et al*., 2018).

Vargas-Ramella *et al*. (2021) reported that *V. meridionale* fruit extracts improved color and lipid stability in pork patties, especially at the highest extract concentration. According to these authors, extracts of *V. meridionale* fruits were added to pork patties without impairing their sensorial profile. The use of *V. meridionale* as a source of natural antioxidant, colorant, or functional ingredients increased the life of patties, burgers, and other ground meat products, which could be employed in the restaurant and fast-food industries (Vargas-Ramella *et al*., 2021).

Garzón *et al*. (2021) stated that *V. meridionale* fruit extracts could be successfully utilized as colorants in yogurts. Fruit extracts of *V. meridionale* were effective in stabilizing Sacha inchi (*Plukenetia volubilis* L.) oil, thus, preventing the oil from oxidizing (Zapata *et al*., 2015). Espinosa-Moncada *et al*. (2018) and Galvis-Pérez *et al*. (2020) emphasized the medical properties of *V. meridionale* fruits.

Since *V. meridionale* is mostly present in wild populations in Colombia, efforts should be made for further domestication of this species. Recent studies on the hybridization of *V. meridionale* have shown that this species produces fertile hybrids with *V. corymbosum* (Ehlenfeldt and Luteyn, 2021), *V. vitis-idaea* (Ehlenfeldt *et al*., 2022), and *V. macrocarpon* (Ehlenfeldt *et al*., 2023), which could be used for *V. meridionale* breeding purposes. Hybrids *V. meridionale* × *V. macrocarpon* (cranberry) had good pollen production and an acceptable pollen quality (Ehlenfeldt *et al*., 2023). Hybrids *V. meridionale* × *V. vitis-idaea* (lingonberry) were vigorous and evergreen, with small, red-colored fruits, and presented good male fertility (Ehlenfeldt *et al*., 2022).

AGRACEJO, *VACCINIUM FLORIBUNDUM* KUNTH

This evergreen species is native to the mountain regions of Colombia, Bolivia, Ecuador, and Peru, where it is also known by the name of "mortiño". It can be a pioneer species in the parámos that starts to grow after fires (Llivisaca-Contreras *et al*., 2022) or mining activity.

V. floribundum has a shrub-like morphology, is highly branching and varies from 0.2 to 2 m in height (Fig. 2). It grows at altitudes between 1,600 and 3,800 m a.s.l. in dry lower montane and humid montane forests and páramos (Luteyn, 2002; Cobo *et al*., 2016). The leaves are small, elliptic, and ovate, with a characteristic violet hue on the leaf margins (Llivisaca-Contreras *et al*., 2022). The flowers are 5-8 mm long, red, pink, or whitish-red, and grouped in racemes consisting of 5-20 flowers; the berries are 5 to 10 mm in diameter and blue or dark blue when ripe (Cobo *et al*., 2016). In the departments of Cundinamarca, Boyaca and Santander, its ecological niche is broader than that of *V. meridionale* since wild populations of *V. floribundum* in these areas tend to expand over a broader altitudinal range (1,800-3,800 m a.s.l.). The plants that are occasionally seen in Colombian highlands at altitudes over 4,000 m a.s.l. have the smallest height (5-20 cm), a "stocky" appearance with short internodes, and a small fruit size (< 5 mm in diameter). This common characteristic of compact shrub-type plants could benefit the cultivation of *V. floribundum* plants as a commercial crop in pots or small containers.

Figure 2. (A) Plant of *V. floribundum* with fruits in the páramo El Verjón (3,200 m a.s.l., Cundinamarca department) and (B) overlapping vegetative and reproductive stages of growth in *V. floribundum*.

Along with *V. meridionale*, this plant is considered a "superfruit" because of the high antioxidant capacity of fruits and their potential health benefits (Pérez *et al*., 2021; Cerrato *et al*., 2022; Utus-Ramíres *et al*., 2023). According to Caranqui-Aldaz *et al*. (2022a), the principal bioactive components of its fruits are hydroxycinnamic acids (5-O-caffeoylquinic acid), flavonols (quercetin 3-hexoside, quercetin 5-hexoside, quercetin 3-pentoside, and quercetin-3-O-rhamnoside), and anthocyanins. Esquivel-Alvarado *et al*. (2020) reported that cyanidin and delphinidin glycosides are the predominant anthocyanins in the fruits of tropical *Vaccinium* species, including *V. floribundum*. The leaves and fruits of *V. floribundum* present antimicrobial activity (Llivisaca *et al*., 2018).

Mature fruits were shown to possess high levels of antioxidants, such as ascorbic acid of 9.0 mg/100 g FW, total phenolics of 882 mg gallic acid equivalent/100 mg FW, and antioxidant activity ABTS of 47.9 μmol Trolox equivalent/g FW (Vasco *et al*., 2009). Consequently, beverages prepared from *V. floribundum* fruits have high contents of phenolic compounds, including anthocyanins, and, therefore, have nutraceutical properties (Utus-Ramíres *et al*., 2023). The fruits could be a good source of micronutrients for human nutrition, especially Fe and Mn (Caranqui-Aldaz *et al*., 2022a).

In several native populations of *V. floribundum* in the department of Cundinamarca (2010-2015), the size of the plants and the size and weight of the fruits decreased with increasing altitude (S. Magnitskiy, unpubl. data). At the same time, the fresh weight of the pulp decreased at a greater proportion than that of the fruit skin. In *Vaccinium* spp., the fruit skin has superior antioxidant activity and higher anthocyanin contents than the pulp (Burdulis *et al*., 2009; Ribera *et al*., 2010), which could potentially increase the anthocyanin contents in *V. floribundum* fruits at higher elevations. According to Guevara-Terán *et al*. (2022), in Ecuador, the highest antioxidant content was found in *V. floribundum* fruits collected at high altitudes, over 3,500 m a.s.l., which can be explained by the climatic conditions in these locations, such as increased solar radiation.

The extracts from fruits may be used as natural dyes according to Taco-Ugsha *et al*. (2020), who characterized pigments from "mortiño" (*V. floribundum*) extracted with different acids and evaluated as natural sensitizers. Huarancca-Huarcaya *et al*. (2022) showed a relative resistance of anthocyanins from *V. floribundum* fruits to thermal degradation when the anthocyanin contents in the fruit extracts decreased by 16.2% after 240 h of heat treatment at 30°C.

Palencia-Argel *et al*. (2022) used fruits of *V. floribundum* to prepare beverages with high level of antioxidants. According to Marracino *et al*. (2022), high consumption of natural antioxidants from *V. floribundum* fruits promotes health by reducing oxidative stress and, therefore, the risk of developing cardiovascular diseases. The extract of *V. floribundum* fruits could be employed in bread baking (Guijarro-Fuertes *et al*., 2018).

Ripe *V. floribudum* fruits possess properties of interest for different industries, such as for the synthesis of photocatalytic nanocomposite materials (Vizuete *et al*., 2016). Anthocyanin molecules in fruits of *V. floribundum* and other *Vaccinium* species have hydroxyl groups that effectively bind with TiO_2 nanoparticles, which are important for the nanoparticle industry (Taco-Ugsha *et al*., 2020; Ringwal *et al*., 2021).

CURRENT CHALLENGES FOR WILD POPULATIONS OF *VACCINIUM* IN COLOMBIA

The native Ericaceae, including *Vaccinium* spp., constitute a valuable genetic resource for this country, which should be used in breeding programs. The use of fruits from the native Ericaceae, such as *V. meridionale*, benefits the development of local markets (Quevedo-Rubiano *et al*., 2021; Weber *et al*., 2021) and could offer new products for international markets. Since these plants have not been completely domesticated, potential uses depend greatly on maintaining their populations in the wild.

In the Andean highlands, current climate changes are expected to produce negative impacts on populations of wild plants. Thus, in the páramo, increasing average temperatures, together with lower precipitation, may reduce the water content in soil, which would impose water stress on plants (Cruz and Lasso, 2021). In adult *V. meridionale* plants, the rate of vegetative growth depends on temperature and rainfall seasonality (dry and rainy periods), while both of these climatic factors are affected by global warming (Medina *et al*., 2019). Therefore, continuous changes in the populations of páramo plants are expected in the future, and some species will be more affected by climate changes than others (Cruz and Lasso, 2021).

Anthropogenic factors, such as unsustainable land use and overharvesting, could have a greater negative impact on populations of native plants than climate change (Rodríguez *et al*., 2018). The ecosystems of the Andes are subject to fragmentation caused by anthropic intervention (Velasco-Linares and Vargas, 2008), including expansion of urban areas. Caranqui-Aldaz *et al*. (2022b) indicated that deforestation, land conversion, and overexploitation of natural resources endanger populations of *V. floribundum*. On the other hand, the reproductive phenology of *V. floribundum* shows no chronological, orderly progression, so different phenological stages (buds, flowers, and fruits) can be simultaneously observed in same individual plants (Caranqui-Aldaz *et al*., 2022b; Fig. 2B). In this way, continuous fruit production and seed dispersal could aid the persistence of *V. floribundum* populations in the wild. Additionally, Ericaceae plants, including *Vaccinium* spp., commonly respond to habitat disturbances by increasing clonal growth through resprouting (Franklin *et al*., 2020), which is a useful adaptive trait to persist on degraded lands (Ocampo-Zuleta and Parrado-Rosselli, 2022).

V. floribundum plants can have a high degree of genetic diversity (HE = 0.73), such as shown in the highlands of Ecuador (Vega-Polo *et al*., 2020). According to these authors, a population structure analysis suggested the presence of distinct genetic clusters in different regions of Ecuador, whereas a separate cluster of *V. floribundum* was found at higher elevations (Vega-Polo *et al*., 2020). A high degree of genetic diversity in populations increases a plant's potential to resist anthropic changes (Arbez *et al*., 2001). However, physical degradation of the páramo, such as through mining, and land use for pastures and traditional crops, including the potato crop, could further affect the persistence of native *Vaccinium* plants.

Apart from their prospective role in the food industry and medicine, native Ericaceae species play an important ecological role. They favor recovery of degraded highlands (Castellanos-Castro and Bonilla, 2011; Sierra-Escobar *et al*., 2020); in particular, the plants of the *Cavendishia* genus repopulate mountain habitats affected by landslides or road construction (Pacheco Flores de Valgaz *et al*., 2022). In the departments of Cundinamarca and Boyacá, plants of *Thibaudia* and *Cavendishia* frequently establish themselves on anthropogenically disturbed areas, such as roadsides, while *Macleania rupestris* ("uva camarona", in Spanish) naturally invades mountain slopes subjected to soil erosion, which implies its possible use for ecological restoration of the páramo. For *V. meridionale* and *V. floribundum*, little information is available on their potential importance for degraded land recovery. According to Llivisaca-Contreras *et al*. (2022), shallow roots and almost horizontally root growth, as well as prolific sprouting, make *V. floribundum* a pioneer species that regenerates damaged ecosystems in the páramo, drawing attention as a species for ecosystem restoration in the Andes. Conservation programs for native *Vaccinium* species should consider a more efficient use of natural environments, such as the creation of protected areas for wild plants, and continuous research on their benefits and further use.

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