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REVIEW ARTICLE

The Mortiño (*Vaccinium floribundum* Kunth): a review of its suitability as a promissory crop in the Ecuadorian Paramo and its potential uses, environmental role, and health benefits

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Abstract

The mortiño (*Vaccinium floribundum* Kunth), belonging to the Ericaceae family, is a native species of the Ecuadorian paramos. It has a shrub-like habit and produces edible fruits. In the Neotropics, it is primarily found in the Andes of Colombia and Ecuador, thriving in humid environments up to an elevation of 3700 m above sea level. In this review, a selection of studies was carried out that evaluated the taxonomy, reproduction biology, and nutraceutical, environmental properties, and industrial use of the mortiño (*V. floribundum*). The data gathered from various bioassays were essential in determining the appropriate techniques for tissue differentiation and assessing the quality of resulting plants. This work aims to generate a deep knowledge of the cultivation of mortiño, as well as the properties of its fruits and the benefits they provide for health. These are rich in compounds with antioxidant activity, so the consumption of *V. floribundum* fruits is related to health benefits. Besides, the environmental role of *V. floribundum* and its applications in various industries, especially in the development of nanoparticles contributes to the valorization of this plant. Overall, this research contributes to establishing sustainable methods for the propagation of *Vaccinium floribundum*, ensuring its successful cultivation and utilization for both commercial purposes and ecological preservation.

Keywords Mortiño · *Vaccinium floribuntum* · Reproduction · Bioactive compounds · Environment · Industry

Introduction

The Mortiño (*Vaccinium floribundum* Kunth), belonging to the Ericaceae family, is an indigenous species found in the Ecuadorian paramos, characterized by a shrub-like structure and edible fruits. Within the Neotropics, its distribution is concentrated in the Andean regions of Colombia and Ecuador, thriving particularly in humid environments up to an elevation of 4350 m above sea level [1]. Across generations in the Ecuadorian paramos, the fruits of this species, commonly referred to as "mortiño," have been predominantly utilized in the preparation of the traditional 'colada morada' on the Day of the Dead [2]. However, factors such as traditional consumption practices, recent promotion for winemaking, and challenges associated with propagation have contributed to the rapid decline of this species [3]. Additionally, populations have faced setbacks due to deforestation, alterations in land usage, habitat fragmentation, and disturbance resulting from its extraction [2]. These fruits boast significant levels of sugars, minerals, antioxidants, B and C complex vitamins, potassium, calcium, and phosphorus [2, 3].

As outlined by Gutierrez & Camacho [4], inhabitants of high Andean ecosystems, acknowledging the potential of this species, have engaged in irrational exploitation. This behavior involves uprooting plants from their natural habitats and cultivating them in unsuitable conditions, thereby inducing a systemic imbalance within the original zone and disrupting the natural development of other plant species dependent on it. Such practices extend to numerous native Andean species due to inadequate knowledge regarding proper propagation techniques. Despite the significance of these plant species

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to the nation, research in this domain is limited, and available information concerning their genera and species remains scarce. There exists a dearth of studies investigating propagation mechanisms or strategies within Ecuador.

According to Pedraza-Peñalosa et al. [5], the Ericaceae family is present in temperate, subtemperate zones, and tropical mountain forests, predominantly thriving in conditions of elevated humidity and moderate temperatures. Remarkably diverse in the Neotropics, this family comprises approximately 900 species, with nearly 94% being endemic. Concentrated mainly in Colombia and Ecuador within the Neotropics, most Ericaceae species are closely associated with the Andes, especially the cloud forests situated between 1000 and 3000 m above sea level. To a lesser extent, they are also found in lower cloud forests (below 1000 m) and paramos (above 3000 m) regions. In Ecuador, there are 22 genera and 221 species, making it one of the most endemic families in the country. Around 44% or 98 species are exclusive to Ecuador, with the sole family species found in Galápagos being *Pernettya howellii*. Due to their specific climatic requirements, the distributions of Ericaceae are severely constrained, both latitudinally and altitudinally. They prefer forest ecotones and are abundant in roadside areas, trails, ravines, and clearings, playing a pivotal role in the Andean Forest succession process. Apart from their ecological significance, several Ericaceae species hold ornamental or edible value in temperate regions. In Ecuador, the fruits of certain species of Ericaceae, such as *V. floribundum* or "mortiño," are consumed locally, in a special drink called "colda morada", typical of the Day of the Dead.

Concerning the conservation status of Ericaceae in the country, a substantial majority of species (89.7%) are under threat, with six species critically endangered, 33 endangered, and 49 classified as vulnerable. Among the non-endangered species, four are categorized as near threatened, and six are classified under the least concern category. The primary threats to the conservation of these species, ranked in order of significance, include deforestation, habitat fragmentation, colonization, and agricultural expansion. For certain paramo species, grazing and human-induced fires pose substantial threats. The percentage of species protected by the SNAP (State Protected Areas Network) is notably low, considering the locations where these species have been recorded: only 21 out of 98 species are found within state-protected areas [5].

Thus, this review intends to give an overview of the importance of *V. floribundum* to Ecuadorian Paramo.

Scientific literature review

This review is organized as a research paper. A scoping review was used to synthesize the evidence and assess the scope of the studies on the topic. This review was based on the PRISMA Extension (PRISMA-ScR) approach [6] for Scoping Reviews. A comprehensive literature search—Scopus and ScienceDirect—was performed in September 2023 (Fig. 1). Text words and controlled vocabulary for several concepts (*Vaccinium floribundum* Kunth, taxonomy, bioactive compounds, reproduction, ethnobotanical, industry) within the titles, abstracts and keywords were used. The focus has been given to studies published in journals included in the Journal Citation Reports. Only research papers that included the experimental design and data treatment were selected. The structure of the review allows a dissection of (i) taxonomic classification and botanical description, (ii) ethnobotanical, floristic and environmental assessment, (iii) reproductive biology, (iv) antioxidant properties and health benefits, and (v) environmental applications and industrial use.

Taxonomic classification and botanical description of the Mortiño

The taxonomic classification of *V. floribundum*, as documented by the APG IV Classification System [7] is detailed as follows:

Class: Equisetopsida C. Agardh
Subclass: Magnoliidae Novák ex Takht.
Superorder: Asteranae Takht.
Order: Ericales Bercht. & J. Presl

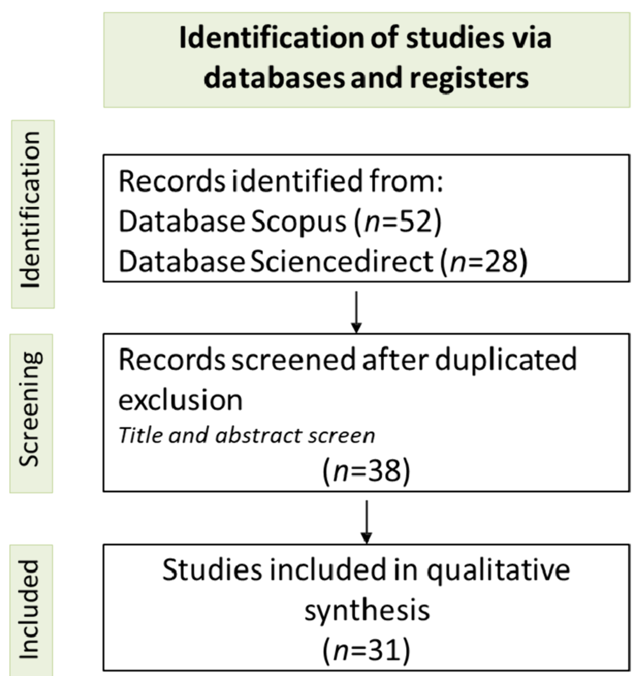

Fig. 1 Flow diagram describing the study selection process of scientific literature

Family: Ericaceae Juss.

Genus: *Vaccinium* L.

These plants typically manifest as shrubs, occasionally as trees, often exhibiting rhizomes. Their leaves, either persistent or deciduous, are arranged alternately, featuring an entire or serrated margin, commonly displaying pinnate veins, occasionally parallel veins, and possessing a short petiole. The inflorescence develops axillary, emerging from the previous season's buds, either in a racemose arrangement or, at times, comprising only 1–2 flowers, borne in the axil of the floral bract or a leaf. Usually, the pedicel includes two bracts. The flowers, typically 4–5-merous, often lack scent; their arrangement is imbricate (as observed in *V. crenatum* and *V. floribundum*). The calyx may either articulate with the pedicel (in Ecuador) or remain continuous. The hypanthium varies from cylindrical to globose, with lobes seldom absent. The corolla, gamopetalous in nature, may appear cylindrical, urceolate, or campanulate, displaying white, greenish, red, or yellowish hues, with lobes occasionally partially divided near the base. The stamens, numbering 8 or 10, are comparable in length to the corolla; their filaments are distinct, longer than the anthers, occasionally possessing spurs (as observed in *V. floribundum*), which may seem vestigial. The anthers lack disintegration tissue, with smooth or papillate thecae; tubules dehisce through terminal pores or, occasionally, oblique clefts. The pollen is devoid of viscin strands. The ovary, entirely or partly inferior, typically contains 4–5 (falsely 10) locules; the stigma is small, simple, or somewhat capitate. The fruit takes the form of a berry, housing 5-many seeds, crowned by persistent calyx lobes and enveloped by a noticeable nectar-producing disc; occasionally, seeds may feature a mucilaginous covering. The *Vaccinium* genus encompasses approximately 300 species, primarily distributed in the Northern Hemisphere, predominantly inhabiting mountainous regions within the tropics; specifically, three species are found in Ecuador [8].

Ethnobotanical, floristic, and environmental assessment

The climatic conditions conducive to the thriving of *Vaccinium* genus species are associated with a specific life zone: humid montane regions characterized by predominantly young and minimally disturbed soils [1].

Most *Vaccinium* species have evolved within mineral-rich soils abundant in organic matter and featuring an acidic pH. The primary limiting factor for blueberry growth is soil pH, with the optimal range falling between 4.2 and 5.2. Soil consistency should be loose and suitably porous to facilitate the superficial and delicate root system's efficient exploration [9].

For the optimal development of *V. floribundum*, ideal agroecological conditions necessitate temperatures ranging from 8 to 16 °C (considered cold), humidity levels between 60 and 80%, an annual precipitation range from 800 to 2000 mm, and an altitude spanning from 3200 to 3800 m above sea level. Soil prerequisites for the propagation of these materials align with characteristics found in high-mountain ecosystems: sandy, humic, loose soils, rich in organic matter, with a slightly acidic to neutral pH [10].

Considering the flourishing nature of Ericaceae in paramo conditions, it is crucial to note that Colombia, with an extensive distribution of paramos mainly across its three mountain ranges, holds substantial potential for the sustainable cultivation and utilization of the Ericaceae family, particularly within the *Vaccinium* genus. Paramos in Colombia are recognized as natural ecosystems with limited and localized human-induced impact [11]. Paramos experience a cold and humid climate characterized by sudden atmospheric changes. While the annual temperature fluctuation remains small (2–10 °C), daily temperature variations range from freezing point to 30 °C. These fluctuations give rise to a daily cycle of freezing, temperature elevation, and intense solar radiation, described by some authors as a "summer every day—winter every night" [12]. The diurnal seasonality in paramos bears a superficial resemblance to the annual seasonality typical of temperate and polar latitudes. The climate is unstable, cold, cloudy, and rainy, interspersed with periods of intense sunlight [13]. In broad terms, blueberries require 650–850 h of cold temperatures below 7.2 °C to ensure abundant and uniform flowering. Additionally, a minimum duration of 160 days is essential for this process. Flowers suffer damage at temperatures below – 1 °C and above 30 °C; in leaves, vegetative growth halts, leading to fruit dehydration [14, 15].

In Ecuador, *V. floribundum* thrives as a wild plant in the elevated regions of the mountain range, spanning from the paramos of El Ángel in Carchi to Tambo in Cañar. Information sourced from the Cotopaxi National Park delineates the adaptation zone for the "mortiño" within the range of 2000 m above sea level to 4500 m above sea level. However, only a few paramos accommodate a significant population of these plants due to the encroachment of extensive agricultural areas on their habitat, confining this species to paramo zones ranging between 3400 and 3500 up to 4500 m above sea level [16].

Based on documented collections, *V. floribundum* is prevalent in the Sierra region across the provinces of Carchi, Imbabura, Pichincha, Cotopaxi, Tungurahua, Bolivar, Chimborazo, Cañar, Azuay, and Loja. Likewise, records indicate the presence of *Vaccinium distichum* and *Vaccinium crenatum* in the provinces of Azuay and Loja [1]. Estrella [17] lists Macleania ecuadoriensis "hualicon," Macleania laurina

Blake "Chaqui-lulu," Macleania popenoei "Joyapa" as edible berries with similar characteristics.

Traditionally, "mortiño" is partaken in a special dish with cane honey, spices, and assorted fruit pieces on the Day of the Dead, often accompanied by the traditional "colada morada," a customary culinary delight in popular culture [17]. Historically, few were acquainted with its specific name, and it is likely that a substantial segment of the urban populace remained oblivious to its existence, associating it more with the family of "agraz" or blueberries.

The "mortiño" is esteemed as a sacred product due to its wild attributes, thereby requiring no specific treatment. Rural communities utilize this shrub to alleviate conditions like rheumatism, fevers, and colic. It is also employed in treating flu, intoxication, liver, and kidney ailments, along with addressing pulmonary issues and weakness [18]. Notably, the "mortiño" stands out as an ideal shrub for ornamental use owing to its shiny, smooth, reddish-purple, and pinkish leaves, often employed to adorn spaces. Through skilled pruning, the shrub can assume decorative shapes that are strikingly appealing. Its leaves serve as fodder for animal feed. Furthermore, the "mortiño" finds use as fuel and in the regeneration of burnt areas as part of reforestation efforts [19, 20].

Reproductive biology

In Colombia, the incorporation of *Vaccinium meridionale* and *V. floribundum* into production systems has been limited, unlike the blueberry crop, which also belongs to the *Vaccinium* genus and serves as a reference. Due to its wild nature, there is a lack of understanding regarding its propagation methods [21]. However, propagation efforts have been conducted with species other than *V. floribundum*, providing a foundation for further research.

A practical and viable method for asexual propagation of *V. floribundum* is through cuttings. This approach offers economic advantages and simplicity, addressing issues of plant incompatibility and low vigor while ensuring greater uniformity and quality in production [22]. Additionally, the natural spread of plants in the Ericaceae family through rhizomes in their native habitat supports the feasibility of this propagation method [22]. In the case of blueberry (*Vaccinium corymbosum*), it is directly propagated through hard cuttings with a diameter greater than 5 mm, or young cuttings with leaves [23]. Rooting capacity varies among species and cultivars, necessitating empirical tests to determine optimal conditions.

Despite the advantages, a challenge in the asexual propagation of mortiño is the low rooting potential of cuttings under controlled conditions. Nonetheless, research indicates that treatments with 3-aceitc acid (IIA) and indole-3-butyric acid (IBA) can enhance the viability of *V. floribundum* cuttings [22].

While there are in vitro propagation techniques for *Vaccinium* sp. [24, 25], these methods are not accessible to fruit producers. In contrast, micropropagation or in vitro propagation has been successfully employed with blueberry (*V. corymbosum*), demonstrating its practical efficacy in obtaining homogeneous plants. This method involves the proliferation of cuttings cultured in a nutritional medium with growth regulators [14, 23]. Notable works by Torres et al. [20] and Debnath [26] have explored protocols for the in vitro propagation of *V. floribundum.*

In terms of sexual reproduction of *V. meridionale*, challenges arise due to difficulties in handling and germination of seeds. Issues include tiny seed size, variations, low germination percentages, potential photoblasticity, and dependence on light for germination [22]. Germination of *V. floribundum* seeds under ambient conditions is not viable without hormones, but in vitro conditions have shown successful germination, albeit with long-term results [4]. *V. floribundum* seeds exhibit innate dormancy under in situ conditions, requiring rest periods exceeding six months to break dormancy. Hypochlorite, when combined with Gibberellic Acid in low concentrations, can disrupt the dormancy conditions of *V. floribundum* seeds [4].

Despite these challenges, aspects related to species propagation and phytosanitary issues with imported propagules limit agricultural production. Therefore, efforts are directed towards meeting market demand with native species due to the similar organoleptic characteristics of *V. corymbosum* and *V. floribundum* [27]. In tropical latitudes, the fruits of the *Vaccinium* genus are marketed on a small scale, and their potential as food or medicine remains to be fully explored. Limited publications exist regarding the use of species from this genus, emphasizing the significance of *V. floribundum* and *V. meridionale* as the most utilized native species [10].

Antioxidant properties and health benefits

According to different studies [2, 28–30], *V. florubindum* berries have relatively high concentrations of sugars, antioxidants such as vitamin C and the vitamin B complex, minerals such as potassium, calcium, and phosphorus. About antioxidants, the mortiño fruit shows a high content of polyphenolic compounds, such as cinnamic acid, flavonols, anthocyanins and anthocyanidins. These compounds have been extensively studied for their ability to neutralize free radicals and protect cells from oxidative stress. The high concentration of anthocyanins contributes significantly to the potent antioxidant capacity of *V. floribundum* [28, 31–33]. Anthocyanins, the pigments responsible for the deep blue color of *V. floribundum* berries, have garnered significant attention in antioxidant research. A study by Ortiz et al. [3] investigated the anthocyanin profile of *V. floribundum* and found a diverse range of anthocyanins, including cyanidin and delphinidin derivatives. The study highlighted the correlation between the anthocyanin content and the fruit's antioxidant activity, emphasizing the potential health benefits associated with these compounds. Caranqui-Aldaz et al. [28] determined that the main constituents of mortiño berries include hydroxycinnamic acids (5-O-caffeoylquinic acid), flavonols (quercetin derivatives), and anthocyanins, and reported three anthocyanins (petunidin, peonidin, and pelargonidin) for the first time in mortiño berries.

The antioxidant capacity of *V. floribundum* has been quantified through various assays, providing insights into its efficacy in scavenging free radicals. In a study by Ramírez et al. [34], the antioxidant activity of *V. floribundum* extracts was evaluated using 2,2-diphenyl-1-picrylhydrazyl (DPPH) and 2,2'-azino-bis (3-ethylbenzothiazoline-6-sulfonic acid) (ABTS) assays. The results demonstrated a dose-dependent scavenging effect, underscoring the fruit's ability to combat oxidative stress.

One of the prominent medicinal properties attributed to *V. floribundum* is its anti-inflammatory effect. Chronic inflammation is implicated in various diseases, including arthritis and cardiovascular conditions. The study conducted by Ramírez et al. [34] explored the anti-inflammatory potential of *V. floribundum* extracts using in vivo models. The results indicated a significant reduction in inflammatory markers, suggesting that the fruit may possess anti-inflammatory properties that could be harnessed for therapeutic purposes. The anti-inflammatory activity of *V. floribundum* is often linked to its flavonoid content. Flavonoids, such as quercetin and myricetin derivatives identified in the fruit, are known for their ability to modulate inflammatory pathways. This study [34] underscores the potential of *V. floribundum* as a natural anti-inflammatory agent. The antioxidant and anti-inflammatory properties of the fruit may contribute to cardiovascular health by reducing oxidative stress and inflammation, both implicated in heart diseases.

V. floribundum has also been investigated for its antimicrobial properties. In a study by Llivisaca et al. [35], researchers examined the inhibitory effects of *V. floribundum* extracts against various bacterial strains. The results revealed a significant antimicrobial activity, suggesting that the fruit may have applications in the treatment of microbial infections. The antimicrobial potential of *V. floribundum* is attributed to the presence of bioactive compounds that interfere with microbial growth and survival.

Environmental applications and industrial use

V. floribundum plays a crucial environmental and ecological role, particularly in paramo ecosystems, as it stands out as one of the initial species to rebound following deforestation and man-made fires [36]. This resilience is attributed, in part, to its robust regenerative capacity, facilitated by propagation from roots and other woody structures [37]. Numerous studies have focused on Mortiño's ability to regenerate areas affected by fire, underscoring its significant contribution to restoring ecosystem structure and acting as a pioneer in ecological succession [36, 37].

Various investigations [37, 38], including those by Ramsay & Oxley (1996) and Llivisaca-Contreras et al. (2022), have demonstrated Mortiño's impressive regenerative activity of *V. floribundum*. These studies highlight its capacity to colonize regions impacted by fires, playing a pivotal role in soil recovery. The shallow roots and horizontally spreading root growth of *V. floribundum*, coupled with prolific sprouting, designate it as a pioneer species adept at regenerating damaged ecosystems in the paramo. Consequently, it has garnered attention as a species essential for ecosystem restoration in the Andes. For effective conservation programs targeting native *Vaccinium* species, it is imperative to consider more efficient utilization of natural environments. This involves creating protected areas for wild plants and fostering ongoing research to understand their benefits and potential applications [39].

Ripe *V. floribundum* fruits exhibit properties that are of interest across various industries, particularly in the synthesis of photocatalytic nanocomposite materials, as demonstrated Vizuete et al. [40]. The study successfully synthesized silver nanoparticles (Ag Nps) using Mortiño berry extract, introducing a novel dimension to Andean fruits in the realm of nanotechnology. This environmentally friendly approach not only underscores the significance of Mortiño berries in green nanotechnology but also opens up new possibilities for other Andean fruits in engineering applications. Characterization techniques revealed that the generated silver nanoparticles were stable, non-aggregated, monodispersed, with a spherical shape and an average size of 20.5 ± 1.5 nm, showcasing a face-centered cubic nature. The anthocyanin molecules present in *V. floribundum* and other *Vaccinium* species' fruits, with hydroxyl groups effectively binding with TiO_2 nanoparticles, hold significance for the nanoparticle industry [41, 42].

A study by Taco-Ugsha et al. [42] confirms that pigments in mortiño are flavonoids of the anthocyanidin group, such as cyanidin-3-galactoside and cyanidin-3-arabinoside. Due to these compounds, mortiño dyes emerge as a potential alternative to artificial sensitizers for solar cell technologies, given their harmless and abundant nature. Dyes extracted from mortiño fruits were utilized as sensitizers in DSSC and characterized through chromatography (HPLC and TLC), FT-IR spectroscopy, and MALDI mass spectrometry analysis. The most abundant compounds in mortiño extracts correspond to cyanidin derivative anthocyanins. Mortiño dye-sensitized solar cells demonstrated a power conversion efficiency between 0.18 and 0.26%, significantly influenced by the acid extraction medium, with the highest value achieved using TFA-acidified methanol [42].

In a study by Vizuete et al. [40], a simple, cost-effective, and environmentally friendly method was reported for the synthesis of Ag-G nanocomposite using Mortiño berry extract as the reducing agent. This green synthesis of Ag-G nanocomposite, involving the reduction of Ag + and graphene oxide, showcases enhanced photocatalytic properties. The resulting material holds promise for addressing environmental concerns and is poised to play a significant role in various industrial applications. The eco-friendly and green reduction method avoids the use of toxic reagents, making it a potential choice for biocompatible materials in future engineering applications [40].

Conclusions

This work provides comprehensive information about taxonomy and environmental development of *V. floribundum*. About reproductive biology, cuttings are the more viable propagation method for *V. floribundum,* due to their simplicity and low cost compared with other methods. Besides, berries of *V. floribundum* showed high amounts of bioactive compounds, mainly polyphenolic compounds, and anthocyanins, which provide this fruit an excellent source of antioxidants that are related to medicinal properties and health benefits. Furthermore, *V. floribundum* presents other uses, such as environmental restoration after deforestation and fires, due to their ecological role and regenerative activity. About the potential industrial uses, some investigations demonstrate that *V. floribundum* could be used for the synthesis of nanoparticles, with the advantage of the elimination of harmful reagents, positioning it as a promising option for biocompatible materials in upcoming engineering applications. All these characteristics and properties make the mortiño a potentially promising plant for the development of medicines, cosmetics, functional foods and new materials, among others, as well as an ideal plant for the regeneration of soils and the environment.

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Declarations

Conflict of interest The authors declare no confict of interest.

Compliance with ethics requirements The authors declare this study was conducted in accordance with ethical guideline and principles.

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